EVALUATION OF ANGULAR DEVIATION OF MINISCREW IMPLANTS USING CONE BEAM COMPUTED TOMOGRAPHY - AN IN VITRO STUDY

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CERTIFICATE

This is to certify that this dissertation titled **"EVALUATION OF ANGULAR DEVIATION OF MINISCREW IMPLANTS USING CONE BEAM COMPUTED TOMOGRAPHY – AN IN VITRO STUDY"** is a bonafide record of work done by **Dr. Vora Sheelkumar Rashmikumar** under my guidance during his postgraduate study period between 2009–2012.

This dissertation is submitted to **THE TAMIL NADU Dr. M.G.R. MEDICAL UNIVERSITY**, in partial fulfillment for the degree of **Master of Dental Surgery** in Branch V – Orthodontics and Dentofacial Orthopedics

It has not been submitted (partially or fully) for the award of any other degree or diploma.

Guided by

V.K. Shakeel Ahmed

RAGAS DENTAL COLLEGE & HOSPITAL CHENNAI

Dr.V.K. Shakeel Ahmed M.D.S
Reader
Department of Orthodontics
Ragas Dental College and Hospital
Chennai

DEPT. OF ORTHODONTICS
RAGAS DENTAL COLLEGE & HOSPITAL

Head of the Department

24/12/11

Prof. (Dr.) N.R. Krishnaswamy M.D.S.
M.Ortho R.C.S. (Edin), Dip N.B. (Ortho)
Diplomate of Indian Board of Orthodontics
Professor & H.O.D
Department of Orthodontics
Ragas Dental College and Hospital
Chennai

Dr. N. R. KRISHNASWAMY
PROFESSOR & HEAD
Dept. of Orthodontics
RAGAS DENTAL COLLEGE & HOSPITAL
2/102. East Coast Road
Uthandi, Chennai-600 119

Principal

Dr. S. Ramachandran M.D.S.,
Ragas Dental College & Hospital,
Chennai

PRINCIPAL
RAGAS DENTAL COLLEGE & HOSPITAL
CHENNAI

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CONTENTS

INTRODUCTION

The use of miniscrew implants (MSIs) has revolutionized the specialty of orthodontics. MSIs are now more commonly being used in clinical practice to enhance orthodontic anchorage. MSI have many advantages including easy placement and removal, immediate loading, low cost and versatility to use in various clinical situations.[21,88] These benefits have led to a rapid rise in the popularity of MSI.

Numerous anatomical sites for MSI application have been presented in the maxilla and mandible[15,16,17,41,44,50,71,108,109,119] . The inter-radicular septum is considered as one of the most commonly used locations for MSI placement when a full complement of dentition is present. [22,75,106,143] Hence, assessment of inter-radicular distance is of utmost importance because it relates to both safety of vital structures and stability of the MSI. Clinically, there could be many instances in which a clinician comes across cases having reduced inter-radicular space at the desired MSI placement site. Factors that would potentially affect the availability of inter-radicular space are proximity of neighboring roots, root form and its anatomy, axial inclinations of teeth due to dento-alveolar compensation in sagittal skeletal discrepancy and ethnic variability.[22,75,105,142] Because of great anatomic variations in the inter-radicular region, it is important to evaluate the anatomy of the desired location for MSI placement and consider different diameters and lengths of MSI for each patient.[76,89,62,76,140]

Several studies have been performed to assess the safe locations in the inter-radicular space for MSI placement, the so called "safe zones" to avoid root damage.[41,109] To determine the ideal diameter of an MSI, few studies have assessed the availability of inter-radicular spaces. [22,75,105,142] A minimum of 1mm of alveolar bone around the MSI has been recommended to preserve the periodontal health. Therefore, when the diameter of MSI and minimum clearance of alveolar bone are considered, the inter-radicular space needed is 3mm to allow for safe MSI placement. MSI length is also related to the safety issue of the periodontium[109].The mean alveolar process width will suggest the ideal length of the MSI's. It might seem logical that a longer implant can provide greater mechanical retention because of greater surface area contacting the bone[4]. But **Park and Cho**[100] have suggested that even a slight deviation from the ideal path can cause root damage with a longer implant.

Successful MSI placement, in both the maxillary and mandibular regions, requires accurate angulation and position in order to achieve safety, mechanical retention and primary stability.[13,27,98,137,138] A deviation from the planned drilling axis in mesio-distal and vertical direction can occur as most clinicians generally insert MSI's without a guide and place it free hand using only panoramic radiographs or periapical films to estimate the inter-radicular space. **Wu et al**[142] reported that MSI insertion without an accurate surgical guide results in 20% of root injuries during positioning. MSI insertion in inter-radicular areas requires appropriate radiologic planning, including a guide for determination of a safer placement site. In recent years, several guides were developed for MSI placement to improve the accuracy of MSI insertion especially in anatomically difficult regions.[5,22,30,38,90,91] Most of these surgical guide systems use 2-dimensional (2D) radiographs which have technical limitations for estimating the precise placement position in the 3 dimensions of space.[5,118,122,130] Hence, the two dimensional radiographic image of such guides does not necessarily reflect its true spatial relationship with adjacent 3-dimensional anatomical structures and is inadequate in eliminating the risk of root damage.[35,60,75,80,111,120,122,130]. It might be preferable to use cone beam computed tomography to assess the inter-radicular space.[23.75,104] In a study by **Kau et al**[54] to evaluated placement of MSI using cone beam computed tomography, it was found that in spite of MSI placement by experienced clinicians, on average 65.7% of the roots were in MSI contact.

It is also considered that bone density is a key factor for the efficiency of MSI stability. Axial deviation of MSI has been considered as one of the potential cause of root damage and other vital structure of the oral cavity[60,75,112]. Despite extensive use there is sparse literature to determine the factors responsible for axial deviation of MSI immediately after inserted. The role of bone density, various MSI lengths, various MSI diameters, inserted methods and their effects on angular deviation of MSI is still a subject seldom discussed and emphasized upon in literature.

Therefore the aim of this experimental artificial bone study was to evaluate the factors influencing the angular deviation of MSIs using cone beam computed tomography.

REVIEW OF LITERATURE

Anchorage in orthodontics is the resistance to unwanted tooth movement. In the field of orthodontics, several methods have been developed to overcome the critical problem of anchorage. Among them, skeletal anchorage systems have gained increasing interest.

MSIs are mainly preferred among the others, because of their comparatively much smaller size. These small dimensions allow an increase in potential intraoral placement sites, even interdentally between the roots. Due to the small size, their placement and removal are simple and the surgical trauma is restricted to the minimum. This means shorter chair time and less pain and discomfort, whilst low cost and the ability of immediate loading could be considered as additional advantages. Despite the many advantages they present, their clinical behaviour is still unclear. The generally accepted protocol for successful and predictable placement of MSIs includes atraumatic surgical technique, short healing period, biocompatible materials, and patient management. An ideal method for achieving stable MSIs in the initial integration stage has not yet been developed. Risk factors that can jeopardize their clinical performance have been attributed to mechanical and biologic reasons and are mentioned below.

I. **Anatomic location and bone parameters:**

MSIs can be placed both in maxilla and mandible, but investigators have shown that placement site may influence their performance. Possible sites in the maxilla are the nasal spine, the palate, the infra-zygomatic crest, the maxillary tuberosities and the alveolar process. In mandible insertions have been reported in the symphysis, the alveolar process and the retro-molar area.

Berens et al[9] (2006) warned not to place MSIs in the lingual side of the lower jaw, due to the technical demand during insertion and the patients tongue interference and observed quite high loss rates on the palatal side of the upper jaw where according to them the mucosal thickness came into play. The palatal mucosa they reported is 5mm thick in some parts which automatically leads to a long lever arm, which is a decisive factor in the loss of the MSI. **Park et al[101]** on 227 MSI showed higher failure rate in the mandible (13.6% for the mandible and 4% for the maxilla). Other investigators could not identify a difference in failure rates between maxilla (15.9%) and mandible (16.4%) **(Miyawaki et al[88]; Motoyoshi et al[92])**

Poggio et al[109] (2006) discussed that in maxilla the best insertion sites are in the anterior and apical portion and in the mandible the safest sites are between first and second molars and premolars. In the mandible the safest sites mesial or distal to the first molar according to **Deguchi et al[33].**

Cheng et al[21] (2004) said MSI in the posterior maxilla had longer survival than in the posterior mandible. MSI in the posterior versus anterior mandible were also prone to failure. This may be attributed to the higher susceptibility to infection in the posterior mandible, mainly because less attached gingiva is available in this region and higher bone density where overheating is more likely to occur**. Bernhart et al[11]** stated that in palate, the mid-palate, and 3 to 6 mm to the paramedian region offer sufficient bony support.

Cortical bone thickness (CBT) and density can vary according to the region of placement. Areas with thick cortical bone are considered the most stable for MSI placement. Since retention depends essentially on the bone-metal interface, the greater the bone, the better the primary stability. On the other hand, the higher the bone density the greater the bone pressure and bone damage during insertion. **Baumgaertel et al**[7] found that CBT decreased from anterior to posterior palate and recommends a placement site in premolar region. The same holds for **Kang et al**[52] who found that the midpalatal area within 1 mm of the midsagittal suture had the thickest bone available in the whole palate. The thickness tended to decrease laterally and posterior. So, when a MSI could deviate from the midpalatal area by more than 1 mm, they recommend placing it not far posterior or using a shorter MSI.

The above studies show that there is evidence that cortical bone thickness (CBT) can have strong influence on primary stability of MSIs. **Motoyoshi et al**[95] **and Motoyoshi et al**[93] found in both studies that success rates in the groups with CBT ≥ 1 mm were significantly higher than those in the groups with CBT ≤ 1 mm. Inter-dentally cortical bone thickness varies in the upper and lower jaw and a distinct pattern appears to be present. The knowledge of this pattern and the mean values of thickness can aid in MSI site selection and preparation.

Root proximity is referred as a critical factor for MSI survival. **Kuroda et al**[66] **(2007)** classified the inserted MSIs according to its proximity to the root. In category I, the MSI was absolutely separate from the root; category II, the apex of the MSI appeared to touch the lamina dura; and category III, the body of the MSI was overlaid on the lamina dura. There were significant differences in the success rates be-tween categories I and II, I and III, and II and III. Although MSIs in all 3 categories in the maxilla and categories I and II in the mandible showed high success rates above 75%, MSIs in category III in the mandible had a low success rate of 35%. He concludes that the proximity of a MSI to the root is a major risk factor for the failure of MSI anchorage and this tendency is more obvious in the mandible.

Motoyoshi et al[94] (2009) in a FE study stimulated four categories of root contact as follows: the MSI touches nothing; the MSI touches the surface of the periodontal membrane; part of the MSI thread is embedded in the periodontal membrane; and the MSI touches the root. Maximum stress on the bone increased when the MSI was close to the root. When the MSI touched the root, stress increased to 140 MPa or more and bone resorption could be predicted.

II. <u>Miniscrew Implant Related Factors:</u>

Differences have been reported between conical and cylindrical shaped MSIs regarding their retention in bone, with the first ones tending to be in an advantageous position. The conical MSIs show greater primary stability compared to the cylindrical ones as found in a study of **Wilmes et al[137] (2008).** He compared the Dual Top MSI and the Tomas pin and found that despite having the same dimensions the Tomas pin types showed less primary stability than the Dual Top MSI. One apparent reason for that is the intra-osseous part of the Tomas pin which is cylindrical, which seems inferior to those having a conical shape.

Kim et al[56] (2008) showed in his mechanical study that the conical group of MSIs showed significantly higher maximum insertion torque (MIT) and maximum removal torque (MRT) than the cylindrical group. He concludes that although the conical shaped MSI could induce tight contact to the adjacent bone tissue and might produce good primary stability, the conical shape may need modification of the thread structure and insertion technique to reduce the excessive insertion torque while maintaining the high resistance to removal

Kim et al[61,62] (2009) compared cylindrical, taper shaped and dual thread MSIs and said that the cylindrical shape had the lowest MIT and MRT in each length. Although taper shape showed the highest MIT in each length, when the values of insertion and removal angular momentum were analysed (IAM and RAM), dual-thread shape showed significantly higher MRT and RAM in each length. Dual-thread groups showed a gentle increase of insertion torque and a gentle decrease of removal torque in contrast to the other shape groups. He concluded that dual-thread shape provided better mechanical stability with high removal torque on the broad range than other shapes. However, due to their higher IAM and time of MIT they need improvement to reduce the long insertion time to decrease the stress in the tissues.

Miniscrew Implant Dimensions:

MSI dimensions are referred to MSI length and diameter. The influence of these two parameters on MSI stability is still under investigation and studies seem to be controversial.

1. **Miniscrew Implant Length:**

Hitchon et al[43] (2003) examined the effects of MSI length (12 mm, 14 mm and 16 mm) by testing 201 MSI-type MSIs in fresh human cadaver specimens. Length was shown to have a statistically significant effect on pull out strength, with longer MSI having a higher resistance to displacement. This might be expected because holding power is directly proportional to the amount of thread engagement as reported by **Lyon et al[79] (1941).**

Fritz et al[40] (2003) reported that 4 mm long MSI offer adequate stability when compared with 6 mm and 8 mm MSI. **Miyawaki et al[88]** do not associate the length of the MSI with its stability if the MSI was at least 5 mm long. Also **Cheng et al**[21] **and Park et al**[102] agree with the above mentioned authors. The short MSI used for the fixation did not jeopardize the performance; this means that longer MSIs did not necessarily result in greater bone support as stated by **Park et al**[101]**.**

On the contrary, **Tseng et al**[132] **(2006)** stated that the length of the inserted MSIs was an important risk factor. They emphasize that the actual depth of insertion of the MSI was more important than its length, the recommended length being at least 6 mm. This is in accordance with dental implantation, where **Winkler et al**[140] stated that the shorter and smaller diameter MSIs had lower survival rates than their counterparts.

Chen et al[20] **(2006)** studied, retrospectively, the relationship between MSI length and the retention rate. Fifty-nine MSIs, either 8 mm or 6 mm in length, with a diameter of 1.2 mm, were placed in 29 patients for orthodontic anchorage. A statistically significant difference was found between the two groups. The success rates of the 8 mm MSIs and 6 mm MSIs were 90.2% and 72.2%, respectively. Also, other studies by **Park et al**[104]**, Kuroda et al**[66] have also shown higher success rates by increasing the length of the MSIs with the same diameter, but the differences were not statistically significant.

Lim et al[75,76] **(2008)** examined the effects of MSI length, diameter and shape on insertion torque. Cylindrical and taper type MSIs with different lengths, diameters, and pitches were tested by placing them in synthetic bone. Their results showed that increasing MSI length resulted in greater insertion torque, suggesting that greater stability could be achieved.

2. **Miniscrew Implant Diameter:**

Ohmae et al[97] (2001) showed that MSIs, 1 mm in diameter and 4 mm in length, placed in the mandibular third premolar region of beagle dogs were able to sustain an intrusive force of 1.5 N for 12 to 18 weeks.

However, **Miyawaki et al[88] (2003)** thought that the diameter of the MSI was significantly associated with their stability. They later reported that 1 year success rate of MSI with a 1 mm diameter was significantly less than that of MSI with diameters of 1.5 and 2.3 mm. They also found that patients with a high mandibular plane angle showed a significantly lower success rate than those with an average or low angle. This could be attributed to the fact that the thickness of buccal cortical bone in subjects with high mandibular plane angle was thinner than that in subjects with a low angle in the mandibular first molar region. They concluded that the wider MSI should be especially placed in patients with vertical facial growth.

Cheng et al[21] (2004), states that MSI types of identical configuration show no difference in their success. **Carano et al[15,17]** have suggested that MSI smaller than 1.3 mm should be avoided, especially in the thick cortical bone of the mandible**.**

A study of **Berens et al[9] (2006)** found that MSI of a diameter of 2 mm in lower jaw increases success rate. They also recommend a MSI diameter of at least 1.5 mm in the palatal upper jaw. **Wilmes et al[137,138] and Lim et al[75,76]** reported that MSI with 2 mm diameter showed significantly higher insertion torque when compared with MSI with a 1.6 mm diameter.

a. Miniscrew Implant Core Diameter:

Minor diameter refers to the inner (or core) diameter of MSIs which can range anywhere from 1.2-1.6 mm. Inner diameter has been reported to be one of the important factors determining pull out strength because the maximum torsional shear strength of the MSI is related to the cube of its diameter; tensile strength corresponds to the square of its diameter.

Huges et al[45] (1972) reported that minor diameter is also important because the strength of the MSI is directly related to it.

Decoster et al[32] (1990) showed that minor diameter had a negative effect on pull out force, with an increase in minor diameter leading to a decrease in pull out force. Increasing the minor diameter from 4 mm to 5 mm decreased the mean pull out force from 277.8 lbs to 247.8 lbs

Carano et al[15,17] (2005) studied the mechanical properties of three commercially available self-tapping MSIs. They suggested that a minor diameter reduction of as little as 0.2 mm can reduce the resistance to breakage of the MSI by 50%. An overall minor diameter of less than 1.5 mm was not recommended for orthodontic applications because humans can apply enough torsional forces to break smaller MSI. However, if placement torque could be reduced through the addition of other design features, it is theoretically possible to further reduce MSI size.

b. Miniscrew Implant Outer Diameter

The orthodontic literature does not contain much information on the effect of outer diameter of MSI on primary stability. However, the orthopaedic literature shows that outer MSI diameter is one of the most important variables in mechanical strength. MSI with greater outer diameter show greater primary stability due to greater surface area in contact with the bone.

Hughes et al[45] (1972) recommended using MSI with a larger outer diameter when greater holding power is desired. The major diameter is the diameter as determined by the outer diameter of the threads. Outer diameters vary widely among and within different manufacturers. MSIs currently available in the market have outer diameters ranging between 1.2 mm and 2 mm. Various diameters of MSIs have been reported to be successful in providing anchorage. There is indirect evidence indicating that outer diameter is important for stability.

DeCoster et al[32] (1990) used a synthetic bone model to determine the maximum bone-MSI pull out force of orthopaedic MSI with various outer diameters. As the major diameter was increased, within a range of 3-6 mm, the mean pull out force also increased in a roughly linearly fashion from 105.4 lbs to 305.8 lbs. Increasing the outer/inner diameter ratio, while holding the other parameters constant resulted in a small, but significant, increase in pull out force.

Wilmes et al[137,139] (2008) studied various parameters affecting the primary stability of orthodontic MSIs. Outer diameter was one of the parameters determined to have an influence on primary stability. Insertion torques of five different MSI types, tomas-pin (Dentaurum, Ispringen, Germany) 08 and 10 mm, and Dual Top (Jeil Medical Corporation, Seoul, Korea) 1.6 × 8 and 10 mm plus 2 × 10 mm, were measured to determine their primary stability. The Dual Top MSI with a diameter of 2 mm achieved the greatest primary stability followed by the Dual Top MSI with a smaller diameter of 1.6 mm.

It has been shown that various MSI factors such as MSI diameter, (**Morrarend et al**[89], **Lim et al**[74]) MSI length (**Parket et al**[104]**, Crismani et al**[28]), pitch and flutes,(**Brinley et al**[13])are all important determinants of holding power.

3. Insertion torque / Pull Out Strength Of Miniscrew Implant:

Insertion torque (IT) is the result of frictional resistance between MSI threads and bone. Axial pull out strength (PS) reflects the magnitude of the PS that the MSI bears before bone rupture. Both methods have been used to determine MSI retention in the bone. A correlation between IT and PS was found by many authors even though other studies concluded that this correlation does not exist.

O'Sullivan et al[98] **(2004)** reported that insertion torque values differ according to MSI type and higher values of insertion torque show higher interfacial stiffness at the MSI-bone interface. Placement torque correlates directly with cortical bone thickness. Other aspects influencing IT are the bone quality and quantity, the drilling hole, MSI characteristics and insertion technique, continuous or intermittent rotation and dry or wet conditions.

Insertion torque is said to determine primary stability (**Deguchi et al**[33]**, Wilmes et al**[138]**).** And as known, a sufficient primary stability measured by insertion torque seems to play a major role for the treatment time survival rate **(Motoyoshi et al**[92]**).** This is also proven in dental implantology. Insertion torque levels must range between certain limits, since very low or very high values can be critical for MSI success.

Motoyoshi et al[92] **(2006)** reported higher loss rates when the insertion torque exceeds 10 Ncm for MSIs with a diameter of 1.6 mm. A torque value of more than 15 Ncm recorded at the time of insertion appears to be one of the critical variables for MSI survival under immediate loading according to **Chaddad et al[19].** The high torque values may result in higher failure rates due to bone compression, local ischemia, necrosis and micro damages **(Wawrzinek et al[136]).**

4. **Miniscrew Implant Loading:**

The time of loading has been investigated in many researches. Many authors support the fact that MSIs can be loaded immediately, but some allow healing periods of some weeks or even months for a better outcome.

Roberts et al[115] (1989) stated that forces between 1 and 3 N did not affect the MSI stability and **Isidor et al[51] (1997)** noticed that high forces tend to damage the interface integration.

Miyawaki et al[88] (2003) suggested that immediate loading of a MSI-type MSI anchor is possible if the applied force is less than 2N. Immediate loading is probably possible because of successful mechanical integration between the MSI anchor and the alveolar bone. This means that if primary stability of MSI is adequate it is possible to load it immediately, which was in agreement with a study by **Kyung et al[68],** who also mentioned that even smallest MSIs can withstand as much as 4.5N of force, whereas most orthodontic applications need forces of less than 3N**.** A finite element analysis found that an immediately loaded MSI should be limited to 50cN of force in a 2 mm diameter MSI. Other studies do not correlate immediate loading and MSI success rate.

Cheng et al[21], (2004) with regard to the magnitude of orthodontic load, found that a load in the range of 1 to 2 N could be well sustained by the MSIs while no significant difference was noted in the magnitude of load between successful and failed MSIs

Liou et al[78] (2004) supplied a 4N loading on the MSIs at the zygomatic buttress of the maxilla to create a mass retraction of the anterior teeth and all 32 MSI remained stable clinically for 9 months. On the other hand, **Buechter et al[14] (2006)** showed that tip forces higher than 600cN resulted in a high risk for osseointegration loss. As for the direction of force, force system generating a moment in the MSI in the unscrewing direction is associated with failure as reported from **Costa et al[26] (1998),** whereas methods of force application do not matter according to **Park et al[101,102] (2006).**

Duration of force may also contribute to MSI stability risk. **Serra et al[119] (2008)** placed 2 mm wide and 6 mm long MSIs in rabbits and analysed interfacial healing 1, 4 and 12 weeks after placement. The immediate 1 N load did not cause significant changes in the fixation of the MSIs after 1 and 4 weeks of bone healing. Nevertheless, after 12 weeks, the loaded group had significantly lower removal torque (RTT) values than the unloaded group.

5. **Miniscrew Implant Insertion angle:**

The angle of MSI insertion is proposed by some investigators to be less than 90°, because an oblique rather a straight insertion is thought to increase contact between MSI and bone**.** The degree of angle proposed varies between authors. A 30° to 40° angulation in the maxilla and a 10° to 20° in the mandible are proposed by **Kyung et al[68,69] (2003)**.

Carano et al[15,17] (2005) also suggested an angulation of 30° to 45° in the maxilla. **Melsen et al[84] (2005)** recommended the placement of MSIs at such an oblique angle both in the maxilla and mandible in an apical direction

Wilmes et al[137,139] (2008) analysed the impact of the insertion angle on the primary stability of MSIs. Two MSIs differing in size were inserted at seven different angles (30^0, 40^0, 50^0, 60^0, 70^0, 80^0, and 90^0) and the insertion torque was recorded to assess primary stability. It was shown that the angle of MSI insertion had a significant impact on primary stability. The highest insertion torque values were measured at angles between 60^0 and 70^0. Very oblique insertion angles (30^0) resulted in reduced primary stability. Based on the above finding, they hypothesized that oblique insertion of MSIs might be advantageous in regions with reduced bone quality.

Wang et al[134] (2008) compared the performance of self-drilling and self-tapping MSIs under orthodontic force and draw the conclusion that insertion torque didn't differentiate in both MSI types inserted in the maxilla.

Su et al[126] (2009), comparing self-drilling and self-tapping MSIs during insertion, found that the self-tapping MSIs typically had a lower insertion torque than the self-drilling MSIs. Based on the displacements under lateral loading, however, both the self-tapping and self-drilling MSIs showed similar resistance to lateral forces.

Pickard et al[107] (2010) studied the effects of MSI orientation on MSI stability and resistance to failure. MSIs placed in human cadaver mandibles were oriented at either 90^0 or 45^0 to the bone surface. Results showed that the MSIs aligned at 90^0 had the highest force at failure of all the groups (342 ± 80.9 N; $P < .001$). In the shear tests, the MSIs that were angled in the same direction as the line of force were the most stable and had the highest force at failure (253 ± 74.05 N; P< .001). MSIs angled away from the direction of force were the least stable and had the lowest force (87 ± 27.2 N) at failure.

6. **Surface characteristics Of Miniscrew Implant:**

The surface of the intra-osseous part of MSI is mostly treated mechanically, but there are also cases where sandblasting and acid etching is performed. Mechanical and surface treatments seem to provide better Osseo-integration and can help to increase their stability. The preference between a large-grit sandblasting and acid etching (SLA) or a mechanical preparation depends on the desired clinical outcome of MSIs, since the type of surface preparation is seemed to influence the degree of Osseo-integration.

Chaddad et al[19] (2008), in a study on the success rates of surface treated MSIs, surface characteristics did not appear to influence survival rates of immediate loaded MSIs. However, **Kim et al[61] (2009a)** stated that the maximum insertion torque value and insertion angular momentum were significantly lower in the SLA group than in the machined group, but showed higher removal energy, indicating that SLA surface treatment had influenced the Osseo-integration potential

Patient-related factors such as age and gender seem not to influence success rates in most publications, although in one study where computed tomography was used measured cortical bone was thinner in females in the attached gingiva mesial to the maxillary first molar. Physical and dental status such as osteoporosis, uncontrolled diabetes, periodontal disease, smoking and pharmacologic prescriptions such as biophosphonates are considered risk factors for classic dental MSIs. It is probably wise to avoid the use of MSIs in these patients **(Reynders et al[113], 2009).**

Soft tissue characteristics are also an MSI maintenance related factor. The necessity of peri-MSI keratinized mucosa for the maintenance of MSI health has long been a debatable issue for endosseous dental MSIs. However, retrospective clinical surveys have failed to reveal major differences in the survival of MSIs placed in keratinized or non- keratinized mucosa. **Warrer et al[135] (1995)** discovered that absence of keratinized mucosa around endosseous MSIs increased the susceptibility of the peri-implant region to plaque induced tissue destruction. This is in accordance to the findings of **Cheng et al[21] (2004)** who found that absence of keratinized mucosa around MSIs significantly increases the risk of infection and failure.

III. Bone Related Factors In Maxilla And Mandible:

a. Thickness of cortical bone

Cortical bone thickness, which is measured with the help of insertion torque and pull-out strengths, is considered to be an important factor affecting MSI primary stability and consequently playing an important role in the success or failure of the MSI.

Salmoria et al[117] (2008) in his study reported that cortical thickness is one of the main factors influencing insertion torque and, consequently, primary stability and failure rate. More screw threads are able to engage into thicker cortical bone which, in turn, translates into greater primary stability.

In orthopaedics, **Cleek et al[25] (2007)** studied the effects of cortical bone thickness on pull-out strength. Their data showed that pull-out strength was significantly correlated with cortical thickness (r = 0.56, p = .002).47 **Dalstra et al** [31]showed that the maximum stress occurs at the cortical bone level when an implant is loaded. Using a finite element model, they showed that increasing cortical bone thickness drastically reduced the peak strain development in the peri-implant bone tissue. This inverse relationship between cortical bone thickness and peak strain development suggests that cortical bone thickness is a key determinant of initial stability.

Motoyoshi et al[95] recommend that the prepared site should have a cortical bone that is more than 1.0 mm thick. They stated that individuals with greater MSI success had significantly higher cortical bone thickness. Cortical bone thickness and insertion torque were significantly greater in the mandible than in the maxilla. **Huja et al[46] (2005)** performed pull-out tests by placing 56 MSIs in the maxilla's and mandibles of beagle dogs. They found a positive correlation between cortical bone thickness and the maximum force at pull-out (Fmax). Fmax was reported to be 134.5 N in the anterior mandible and 388.3 N in the posterior regions of the mandible. They also showed that the posterior regions of the jaws had thicker cortical plates and greater pull-out values. In another study, **Huja et al[47] (2006),** found peak pull-out strength to be directly related with cortical bone thickness at 6 weeks post-insertion in a canine model. **Salmoria et al[117]** found that cortical bone thickness had a direct effect on pull-out strength. They measured pull-out strength and cortical bone thickness at the time of placement and 60 days after placement. After 60 days, both the thickness of the cortical bone and the pull-out strength had decreased. Bone had resorbed around the neck of the MSI. They concluded that there was a correlation between axial pull-out strength and cortical bone thickness.

b. Bone mineral density

As a method for classifying bone quality, **Lekholm et al[72] (1985)** categorized the jaws into Q1 to Q4 according to bone quality using the ratio of cortical to spongy bone as follows: Q1, almost the entire jaw is composed of homogenous compact bone; Q2, a thick layer of compact bone surrounds a core of dense trabecular bone; Q3, a thin layer of cortical bone surrounds a core of dense trabecular bone with favourable strength; and Q4, a thin layer of cortical bone surrounds a core of low-density trabecular bone.

Misch et al[86] (1990) classified bone density into 4 categories based on the hardness of compact and spongy bone as follows: D1, dense compacta; D2, thick porous compacta and coarse trabecular; D3, porous compacta and fine trabecular; and D4, fine trabecular. They suggested a treatment plan according to each classification. Generally, D1 bone might be located in the lower anterior or posterior regions but is quite rare. D2 bone is common in the mandible at approximately two thirds of the lower anterior, approximately half of the lower posterior, and approximately one fourth in the maxilla. D3 bone is common in the maxilla at approximately half of the upper posterior, approximately 65% of the upper anterior, approximately 23% of the lower anterior, and almost half of the lower posterior. D4 bone is found in the maxillary posterior.

On the other hand, bone density is strongly related to bone strength; the compressive strength of bone is proportional to the square of density **(Carter et al[18], Rice et al[114]).** Methods for measuring the bone density include measuring bone mineral density by quantitative CT **(Lindh et al[77])** or dual-energy x-ray absorptiometry **(Pouilles et al[110])** measuring the Hounsfield units from the CT images, **(Berman et al[10])** and measuring the blackness in the film or the panoramic mandibular index from conventional radiographic images. (**Benson et al[8], Klemetti et al[64])** Conventional radiographs, such as panoramic radiographs, measure bone density by measuring the blackness in the film. Therefore, bone density is affected by bone thickness, which can be a source of error. It is believed that the blackness in the film is affected by exposure time, projection angulation, or development conditions. To standardize the blackness in the film, the radiographs can be taken with a step-wedge attachment on the film as a reference, and the thickness of the reference can be expressed in gray scale on digital images. However, these methods might not reflect bone changes accurately. **(Kim et al [55], Lee et al[70])** One method for measuring bone density appropriately is CT. Three-dimensional CT images are computerized 3D images of 512 X 512 pixels with a slice thickness described as the slice gap of the image scans, and each image point is called a voxel, which contains 12 bit data and can be described in Hounsfield units.

Hounsfield units are standardized according to the attenuation coefficient of water: water, 0 HU; air, –1000 HU; and enamel, 13000 HU. They can be used to identify tissues because of their quantitative properties. **Duckmanton et al[34]** reported that Hounsfield density measurements can help to estimate the quality of bone and also the prognosis of implants. **Norton et al[96]** reported a strong correlation between the objective scale of bone density based on the Hounsfield units and the subjective quality score. **Misch et al[85]** expressed numerically the subjective bone density obtained mainly from experience and tactile sensation, and classified the bones into 5 categories according to density: D1, .1250 HU; D2, 850-1250 HU;

D3, 350-850 HU; D4, 150-350 HU; and D5,\150 HU. Cone beam CT (CBCT) was recently developed for dental use and has the advantage of obtaining 3D images of the maxillofacial area at low cost with less radiation (**Sukovic et al[127]).** However, in this study, conventional medical CT was used to measure bone density because there is no standardization of Hounsfield units in CBCT. A recent study regarding bone density assessments of dental implant sites with both CBCT and medical CT showed that bone density values were generally higher for CBCT even though the correlations between the CBCT and CT values were high. **(Aranyarachkul et al[3])** On the other hand, standardized calibrations have been used for medical CT scanners.

High failure rates and bone loss have been associated with dental implants in low-quality bone. Previous knowledge about bone density is therefore paramount for correct planning and placement of dental implants. **(Pouilles et al[110], Berman et al[10], Benson et al[8], Klemetti et al[64])**

Quantitative computed tomography (CT) is an effective method for bone mineral density (BMD) measurement of specific regions of interest (ROI). A main advantage is that the resulting image is not influenced by adjacent structure superimposition **(Kuroda et al[66]).**30 Its high sensitivity for tissue differentiation allows for a detection threshold of 1% or lower in density difference **(Kravitz et al[65])**. BMD quantitative values in Hounsfield units (HU) for 4 regions are .850 HU (anterior mandibular region), 500 to 800 (posterior mandibular and anterior maxillary regions), and 0 to 500 (posterior maxillary region). (**Ebbessen et al[36])** Because a positive correlation of the pre-operatory quantitative-assessed CT mandibular BMD with torque intensity during implant placement has been found, CT-measured BMD can be used to estimate primary implant stability. **(Cummings et al[29], Misch et al[86,87], Albrektsson et al[1], Vitral et al[132], Ibanez et al[48])**

Although a few studies have used conventional radiography **(Schnelle et al[119])** or CT38-41**(Norton et al[96], Lekhlom et al[72], Shahlai et al[122], Ikumi et al[49])** for bone quantification before implant placement for orthodontic anchorage, they are limited because only bone quantity was assessed. Bone quality (density) surrounding the implant might also have an impact on implant stability. **(Lekhlom et al[72])** Bone quality at the placement site is a possible factor interfering with MSI stability. **(Maino et al[81,82], Heymann et al[42], Park et al[100-105], Miyawaki et al[88])** Although CT-assessed BMD is routine for conventional intra0osseous implants; it is not assessed when MSIs are used as anchorage devices.

Choi et al[22,23] (2009) studied bone density at orthodontic implant sites (30 in the maxilla, 30 in the mandible) in Hounsfield units under simulated placement of MSIs by using 3D maxillofacial CT scan data obtained from 30 adults with normal occlusion. They reported the following:

1. In a comparison of the bone density according to the depth at each site, bone density tended to decrease with increasing depth, particularly in the posterior area.

2. Mean bone density showed a progressive increase from the posterior to the anterior except for the mandibular buccal side, which had no significant differences.

3. A comparison of mean bone density between the buccal and lingual sides in the mandible showed that the lingual side had higher values in the anterior area and vice versa in the posterior area. On the other hand, there were no distinct differences between the buccal and lingual sides in the maxilla.

4. A comparison of mean bone density between the maxilla and the mandible showed that the mandible had higher values, and these differences were more significant in the buccal side of the posterior area.

These results suggest that the differences in bone density according to depth and area should be considered when selecting and placing MSI implants for orthodontic anchorage.

IV. Osseointegration Of Miniscrew Implant:

As widely known, osseointegration is not assumed for MSIs as only the mechanical contact between bone and implant interface is necessary to provide stability. This is the reason of immediate loading ability of MSIs, since no healing period is awaited. However, osseointegration in MSIs was found to be present in many studies and these investigators recommend a waiting period prior to force application.

Melsen et al[83] (1998) experimentally investigated the Aarhus MSI by inserting them in the infra-zygomatic crest and the mandibular symphysis of Macaca monkeys and immediately loading the implants with a force ranging between 0.25-0.50 N in 1 to 6 months period of time. Histological the screws exhibited a degree of osseointegration varying from 10 to 50 % which was time dependent, but independent of the type of bone and the amount of applied force.

Because complete osseointegration of MSIs used in orthodontic therapy is not wanted due to the complications during removal, most of them are manufactured with a smooth surface which impairs the development of bone formation. Despite a small amount of osseointegration that may occur, it is thought that removal is not difficult since coherence is relatively low as active remodelling and less mineralized bone formation takes place in the bone around the loaded screw part **(Serra et al[120], 2008).**

Zhao et al[144] (2009) in a study of different healing times before loading found that 3 weeks is an important time point for implant-bone units to gain biomechanical strength and integration. Osseointegration found after CT scans and maximum force during pullout testing were significantly correlated with healing time.

V. Guides Used For Placing Miniscrew Implant:

When it is necessary to place MSIs near delicate anatomical structures such as the roots of teeth, the maxillary sinus, or the alveolar nerve, a surgical guide can be used to precisely locate the placement point and the vector to avoid damage to the adjacent structures.

After reviewing articles written about MSI usage in orthodontic treatment, it was concluded that there are many devices used in locating MSI placement. These methods can be lumped into 3 categories: wire or metallic guides surgical templates and other devices and methods.

1. Wire and metallic guides

Park et al[101-106], Morea et al[90], Bae et al[4] and **Suzuki et al[128-130]** suggested that a wire guide is a practical radiopaque marker formed from a brass or stainless steel wire. It is inexpensive simple to fabricate and easy to use but it provides limited 2D info on the MSI site. **Choi et al[22,23] (2007)** said that because relative positions may be inconsistent in different radiographic views the wire and metallic guides are not always accurate. Furthermore because guides do not prevent deviation of the pilot drill they do not eliminate the risk of root damage **(Suzuki et al[128-130])**. A **Kim** stent is a 3D method for positioning MSIs that prevents root damage and improves the insertion success rate. The wire guide (0.0215 X 0.0280 inch wire) consists of two parts a positioning gauge which is attached to the tooth distally to the mini MSI placement site and a directional guide which is attached to the tooth mesially to the MSI.**(Choi et al[22,23])**

Surgical templates: **Cousley et al[27]** made surgical stents guides and templates that can transfer a radiologically planned 3D MSI position to the surgical site more accurately than wire or metallic guides. **Kyung et al[68,69] (2003)** used vertical and mesio-distal measurements from a lateral cephalogram to construct an acrylic marker but this provides only a 2D location. **Kitai et al[63] (2002)** described a technique requiring several complicated and expensive steps: a CT scan of a template in the appropriate position, a digital surface scan of the working cast and template, production of a stereolithographic model and fabrication of an acrylic or prefabricated removable stent.

Morea et al[90] (2005) designed an acrylic stent with a metal sleeve to guide the pilot drill for non-drilling SI but the initial wax fixation of the sleeve to the working cast seems fragile. There appears to be no access for external irrigation and retention of the acrylic stent may be problematic32.

Cousley et al[27] (2006) modified the 3D stent 26. The design and fabrication are simple and the stent provides reliable guidance for either the pilot drill or the self drilling MSI in terms of both location and angulation. The stent allows access for both visual monitoring and saline irrigation but this takes time and effort for the laboratory work and fine adjustments cannot be made.

2. 3 Dimensional Radiographic Guides For Miniscrew Implant Insertion:

Suzuki 3D guide[129] (2007) consists of a vertical arm (available in 5,7 and 9 mm). One end is attached to the main orthodontic archwire with a gurin lock and the other end is connected to a stainless steel tube 5mm long and 3mm in diameter. The tube is used to identify the optimal MSI site on bitewing radiographs and guide the drilling of the pilot hole and placement of the MSI. The Suzuki guide has a simple design is adjustable in the horizontal direction and is comfortable for the patient46.

Estelita et al[38,39] (2006) made 3D radiographic surgical guide consisting of 2 items. The first is a 0.045 inch stainless steel telescopic tube soldered to the end of a vertical arm which is attached to a horizontal arm by a gurin lock. Both arms are made of 0.021 X 0.2 stainless steel wire allowing the guide to be inserted into the fixed orthodontic appliance. The second is a modified radiographic positioner.33

3. Methods For Assessing Miniscrew Implant Placement:

There have been various efforts to standardize the proper positioning of MSI **(Carano et al[15-17], Maino et al[82], Bae et al[4]).** 4,5 7,13 The placement site is critical to ensure a successful outcome, but the more important point is the MSI guide itself. **Bae et al[4]** reported on a guide wire that provides a reference in the x-rays. However, wire guide systems require several x-rays for determining the proper position; this limits accuracy during drilling. The wires can be deformed or bent in the oral cavity during x-ray taking. **Maino et al[81]** used resin guides and several x-rays with the long-cone parallel method, but this approach is technique sensitive. To overcome these drawbacks, another type of surgical guide was introduced for the orthodontic MSI, similar to a prosthetic MSI guide. **(Morea et al[90])**

A drawback is that accurate reproducibility of the alveolar bone cannot be obtained with the drilling position when arbitrarily estimating the midpoints of the 2 adjacent teeth on the plaster model. It means that accurate positioning of the drill direction (vector) is still difficult.

However, previous orthodontic guides are based on surface anatomy and compromised x-ray images that do not allow accurate analysis of bone volumes and vulnerable areas—e.g. maxillary sinus, dilacereated roots, or altered bone surface topography due to alveolar bone loss. The sinus can be penetrated during MSI placement**. (Raghoebar et al[111])** Also, the placement site decision is available mesiodistally, but the vertical positions of the crown-to-root areas are difficult to determine. When the placement point of the MSI is known, the axial inclination of the pilot drill and then the MSI are difficult to replicate. To consistently and accurately determine these relationships, 3- dimensional (3D) computed tomography (CT) is suggested.

Seong-Hun Kim et al[58] (2007) illustrated a new surgical guide system that uses cone-beam computed tomography (CBCT) images to replicate dental models; surgical guides for the proper positioning of orthodontic MSI were fabricated on the replicas, and the guides were used for precise placement. The surgical guide was placed on the clinical site, and it allowed precise pilot drilling and accurate placement of the MSI. They concluded that CBCT imaging allows remarkably lower radiation doses and thinner acquisition slices compared with medical computed tomography. Virtually reproduced replica models enable precise planning for MSI positions in anatomically complex sites.

VI. Cone Beam Computed Tomography:

Scarfe W et al[118] (2006) stated that the volumetric data set comprises a 3D block of smaller cuboid structures, known as voxels, each representing a specific degree of x-ray absorption. The size of these voxels determines the resolution of the image. In conventional CT, the voxels are anisotropic — rectangular cubes where the longest dimension of the voxel is the axial slice thickness and is determined by slice pitch, a function of gantry motion. Although CT voxel surfaces can be as small as 0.625 mm square, their depth is usually in the order of 1–2 mm. All CBCT units provide voxel resolutions that are isotropic — equal in all 3 dimensions. This produces sub-millimetre resolution (often exceeding the highest grade multi-slice CT) ranging from 0.4 mm to as low as 0.125 mm (Accuitomo).

Liang X et al[73] (2010) compared image quality and visibility of anatomical structures in the mandible between five Cone Beam Computed Tomography (CBCT) scanners and one Multi-Slice CT (MSCT) system. One dry mandible was scanned with five CBCT scanners (Accuitomo 3D, i-CAT, NewTom 3G, Galileos, Scanora 3D) and one MSCT system (Somatom Sensation 16) using 13 different scan protocols. Visibility of 11 anatomical structures and overall image noise were compared between CBCT and MSCT. Five independent observers reviewed the CBCT and the MSCT images in the three orthographic planes (axial, sagittal and coronal) and assessed image quality on a five-point scale. He reported significant differences were found in the visibility of the different anatomical structures and image noise level between MSCT and CBCT and among the five CBCT systems ($p = 0.0001$). Delicate structures such as trabecular bone and periodontal ligament were significantly less visible and more variable among the systems in comparison with other anatomical structures ($p = 0.0001$). Visibility of relatively large structures such as mandibular canal and mental foramen was satisfactory for all devices. The Accuitomo system was superior to MSCT and all other CBCT systems in depicting anatomical structures while MSCT was superior to all other CBCT systems in terms of reduced image noise. Concluding he said that CBCT image quality is comparable or even superior to MSCT even though some variability exists among the different CBCT systems in depicting delicate structures. Considering the low radiation dose and high-resolution imaging, CBCT could be beneficial for dentomaxillofacial radiology.

Al-Ekrish et al[2] (2011) investigated the accuracy and reliability of linear measurements of edentulous ridges recorded from 16-row multidetector CT (MDCT) images and cone beam CT (CBCT) images acquired using a flat panel detector (FPD) with a large field of view (FOV), both independently and in comparison with each other. Edentulous areas of human dry skulls were marked with gutta-percha markers to standardize the plane of the transverse cross-sections and path of measurements. The skulls were imaged using a 16-row MDCT scanner and a CBCT device with a large FOV and a FPD. Ridge dimensions were recorded from reformatted sections by two observers and compared with measurements recorded directly from the bone. The measurement errors and intra and inter examiner reliability were calculated for each modality and compared with each other. They reported that the overall mean of the absolute errors was 0.75 mm for MDCT and 0.49 mm for CBCT. The mean of the CBCT absolute errors was smaller than that of the MDCT absolute errors for the overall data, as well as for the site-specific data. The intra-examiner reliability score was 0.994 for MDCT and 0.995 for CBCT. The inter-examiner reliability was 0.985 for MDCT and 0.958 for CBCT. Concluding he said that both MDCT and CBCT were associated with a clinically and statistically significant measurement error. CBCT measurements were significantly more accurate than those of MDCT. The measurements recorded from both modalities had a high inter and intra-examiner reliability. Accuracy of measurements was found to be more operator dependent with CBCT than with MDCT.

MATERIALS AND METHODS

Miniscrew Implants (MSI)

Titanium MSI's and the MSI screw-driver used in this study were made by S.K.Surgicals (Pune, India). MSI were of self-drilling type. Different lengths (6mm, 8 mm and 10 mm) and diameters (1.3mm, 1.5mm and 2mm) were used in this study.

Artificial Bone Block:

Experimental artificial bone blocks were used in this in-vitro study was made by Sawbones© (Sawbones; Pacific Research Laboratories Inc, Vashon Island, WA, USA). The bone blocks included in this in-vitro study had three combinations of differing densities (Fig.1) 10pcf, 20pcf and 30pcf (pcf is pounds per cubic foot).[56,76,125] Each artificial bone block used in the study was custom made by the company having 120 x 170 x 41mm dimensions with a 1mm thick cortical bone made of epoxy filled sheet laminated on cancellous bone of varying density. Mechanical properties of the synthetic bone blocks are given in the table 1.

Each bone block was calibrated using graph sheet which was stuck on the surface of 1mm cortical thickness epoxy sheet (Fig.2). Using the graph sheet bone blocks were divided into 4 different columns. First column denotes different lengths (6mm, 8mm and 10mm) of MSI used. Second column denotes the different diameters (1.3mm, 1.5mm, and 2mm) of MSI. A third and fourth column denotes the methods of MSI placement using the surveyor method (guide) and the free hand placement respectively. A midpoint of each square is marked on the graph sheet, where the MSI of various lengths and various diameters will be inserted perpendicularly either using the surveyor method (guide) or the free hand placement respectively (Fig.2).

Method of MSI insertion

Two methods of MSI insertion were used,

- First method of MSI insertion was with the help of surveyor to mimic clinical situation using a guide and
- Second method of MSI insertion was free hand placement without a guide.

Surveyor method (Guide)

A surveyor by Saeshin Company (Saeshin Precision Co., Ltd., Korea) was used as a guide for perpendicular insertion of the MSI. The MSI screw driver provided by the company (S K surgical) had to be modified to fit into the surveyor assembly (Fig.3).The surveyor unit has a spring located at the top of the assembly which was removed so that it does not give any recoil force on the hand of the operator while inserting MSI. Tilt-top stand in the surveyor to keep the dental cast was removed so that uniformly flat surface was provided to place the artificial bone block. The pin and tube device of the modified MSI screw driver was fitted in the surveyor assembly (Fig.4).

In the surveyor guided placement method, the MSI were inserted using the modified MSI driver which was attached to the surveyor (Fig.5). MSI head was locked in the modified MSI driver to obtain a firm grip. It was ensured that each MSI was inserted in the perpendicular direction; it also prevented wobble of the driver during insertion. After engaging the MSI head, the tip of the MSI contacted the surface of the artificial bone block perpendicularly at the pre-determined point calibrated on the graph. The modified MSI driver was rotated in clockwise direction with finger pressure until the point right before head of the MSI came in contact with the bone surface (Fig.6 a, b ,c and d; Fig.9 and.10)

Free hand placement (without guide)

Free hand placement was defined as MSI placement using regular MSI driver provided by company without a guide according to the manufacturer's instructions. In the free hand placement method the MSI head was locked in the MSI driver to obtain a firm grip (Fig.7). It was ensured that each MSI was inserted in the perpendicular direction; it also prevented wobble of the driver during insertion[90,91] (Fig.8 a, b, c and d). After engaging the MSI tip to contact the artificial bone block perpendicularly at the pre-determined point, the operator rotates the MSI driver in a clockwise direction with a finger pressure until the point right before head of the MSI came in contact with the bone surface (Fig.9 and 10)

The above methods of MSI insertion were done in the 3 different bone density blocks (10pcf, 20pcf and 30pcf) respectively. A CBCT scan was done for each bone block after MSI insertion.

Cone Beam Computed Tomography (CBCT) scan and analysis

A cone beam computed tomography (CBCT) scan was done for each artificial bone blocks having 3 different bone densities (10pcf, 20pcf and 30pcf) were taken respectively. Each bone block was placed on the stand provided in the CBCT unit. A median beam line was used to centre the artificial bone block and the head-holding rod was used to hold the bone block in a stationary position (Fig.12).

CBCT scans for the experiment study were performed using a Kodak 9500 unit (Kodak Dental Systems, Carestream Health, Rochester, NY, USA) with the following standardized parameters : 90 Kv; 4Ma; Field Of View (20 X 18 cm);acquisition time 24 seconds; voxel size 0.3mm). The CBCT data were saved as a digital imaging and communications in medicine (DICOM) file by using the Kodak Dental Imaging Software 3D Module Version 2.4.

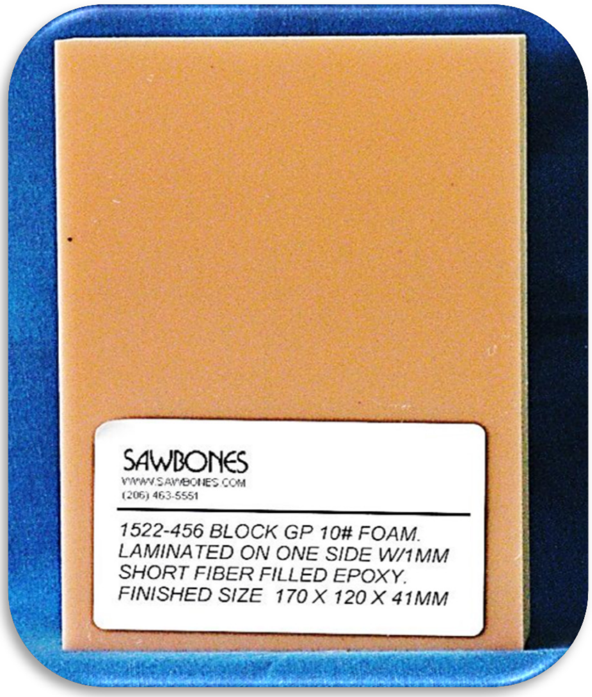
Measurements:

Measurements are carried out by the following criteria:

The Kodak software provided along with the cone beam computed tomography scan (CBCT) was used to measure the angular deviations of MSI. Tools for angular measurement provided along with the software were used in the study (Fig.13). In each scan the measurements were obtained in mesio-distal or horizontal (view 1; Fig.14) and occluso-gingival or vertical (view 2; Fig.16). In each bone block a perpendicular plane was constructed on the bone surface to measure the angular deviation of the inserted MSI. The long axis of each MSI inserted perpendicular into the bone block was marked using the point tools provided in the CBCT scan from the center of MSI head to the tip of the MSI. The long axis was then superimposed on the constructed perpendicular on the bone surface to obtain the degree of MSI angular deviation in both mesio-distal plane or horizontal (View 1) and occluso-gingival or vertical plane (View 2) respectively (Fig.15 and.16). Measurements were recorded in degree. If the angular deviation of MSI was 1 degree or less than 1 degree, it was considered as an acceptable angular deviation. If the angular deviation of MSI were more than 1 degree, it was considered as an unacceptable angular deviation. Measurements of angular deviation were recorded in both views (View 1) and (View 2) respectively to assess which factors were responsible for the angular deviations (various lengths, various diameters, method of MSI insertion and different bone density). For each bone block angular measurements were measured and recorded. This procedure was repeated 10 times after a 2 day interval to reduce intra-observer variability.

Statistical analysis:

Data entry and statistical analysis was performed with using the SPSS v.15 (SPSS Inc., Chicago, Illinois, USA). Descriptive Statistics was done for assessing the angular deviation with respect to varying lengths, varying diameters, different bone densities and methods of MSI insertion. Descriptive statistics were done to find the lowest and highest values of each group, as well as the mean value and standard deviations. To evaluate the significance of the individual parameters influencing the angular deviation One Way ANOVA Test with 95% confidence interval was performed. Cross Tabs Analysis were done to find out the acceptable and non-acceptable degree of angular deviation of MSI. Univariate Logistic Regression was done to assess the major factor influencing the angular deviation of MSI and Odd's Ratio was presented. P value < 0.05 was considered statistically significant.



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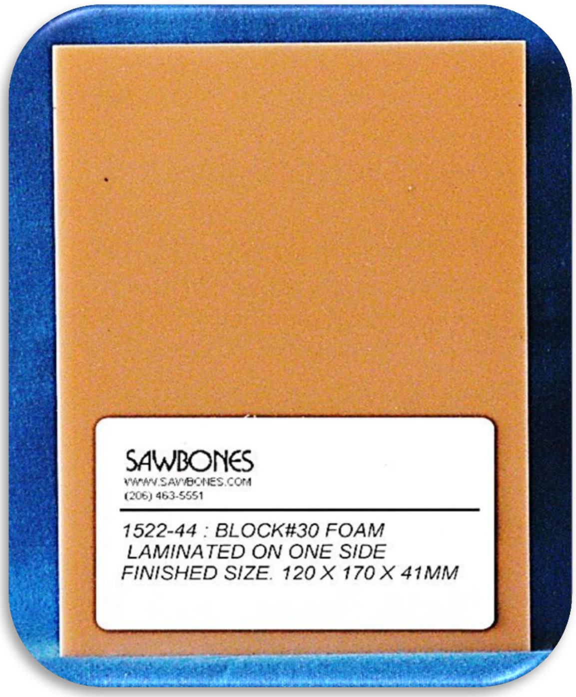
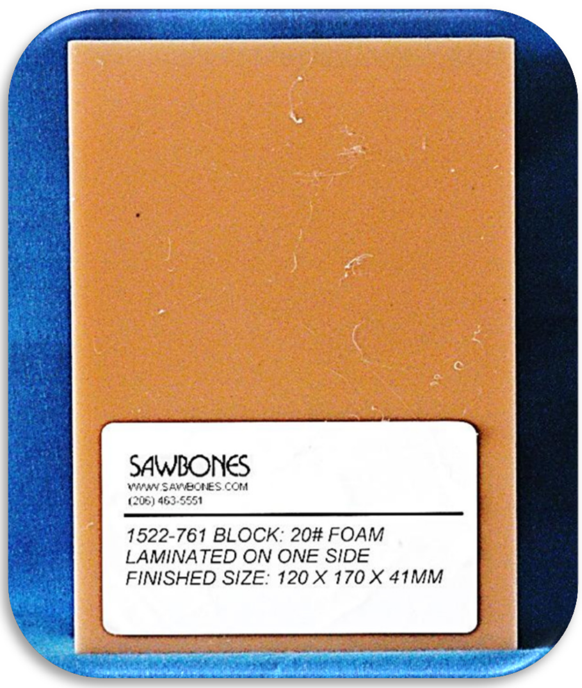


20 pcf



30 pcf

Figure 1: Polyurethane Bone Blocks with 3 different bone densities (10;20;30pcf) with 1mm Epoxy Sheet

Figure 2: Synthetic Bone Block Caliberated with Graph Sheet

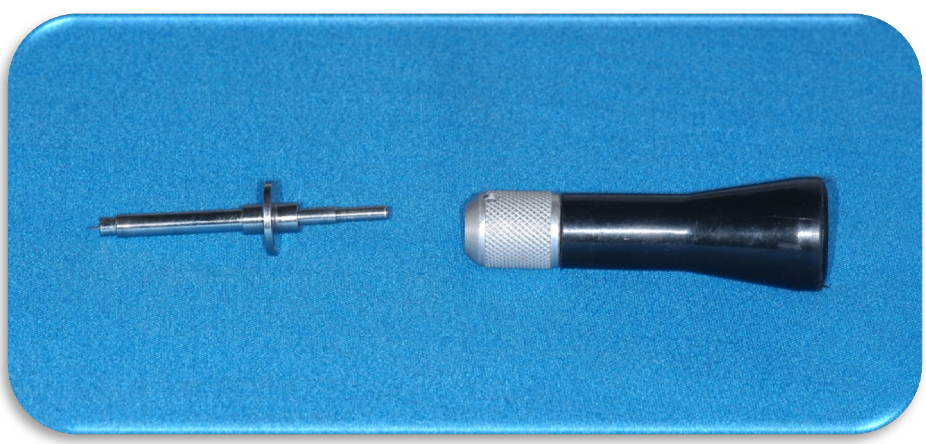


Figure 3: Modified MSI Screw-Driver.

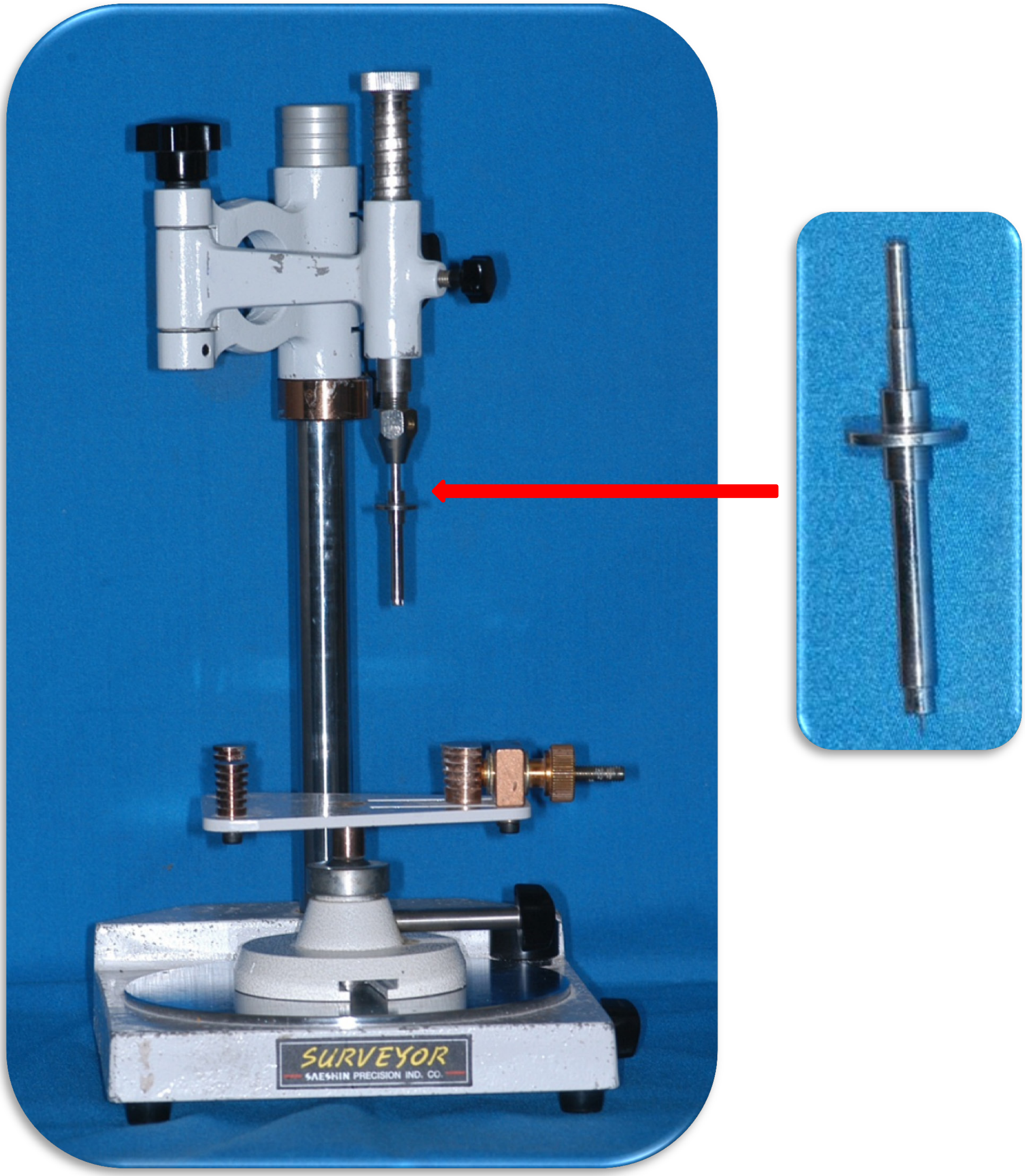
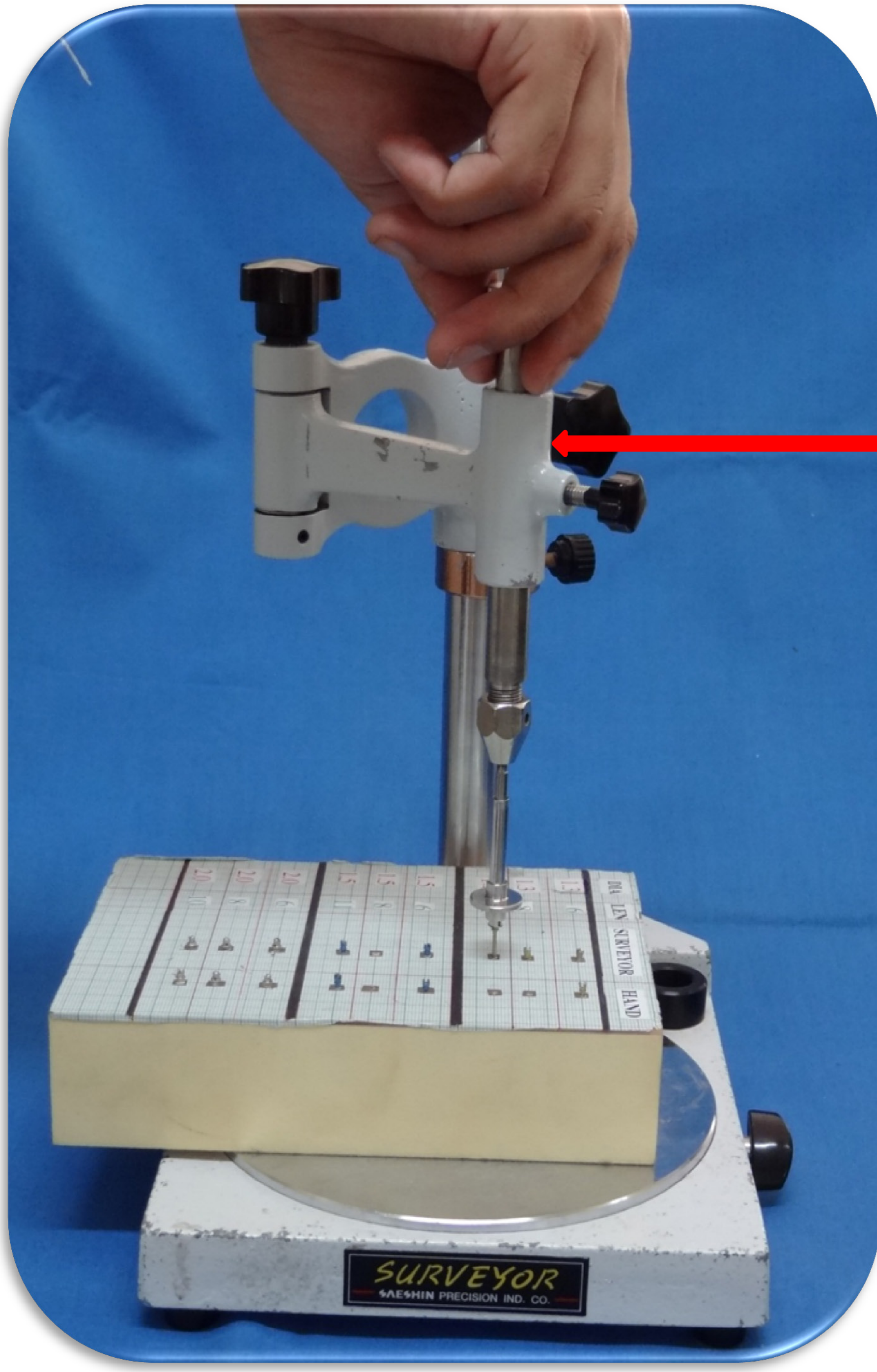


Figure 4: Saeshin Company Surveyor Assembly Fitted with Modified MSI Driver



Guide for Perpendicular Path Of Insertion

Figure 5: MSI Insertion with Surveyor as Guide

a

b

c

d

Figure 6: MSI Inserted In Homogenous Density Bone Blocks With Surveyor Method As Guide

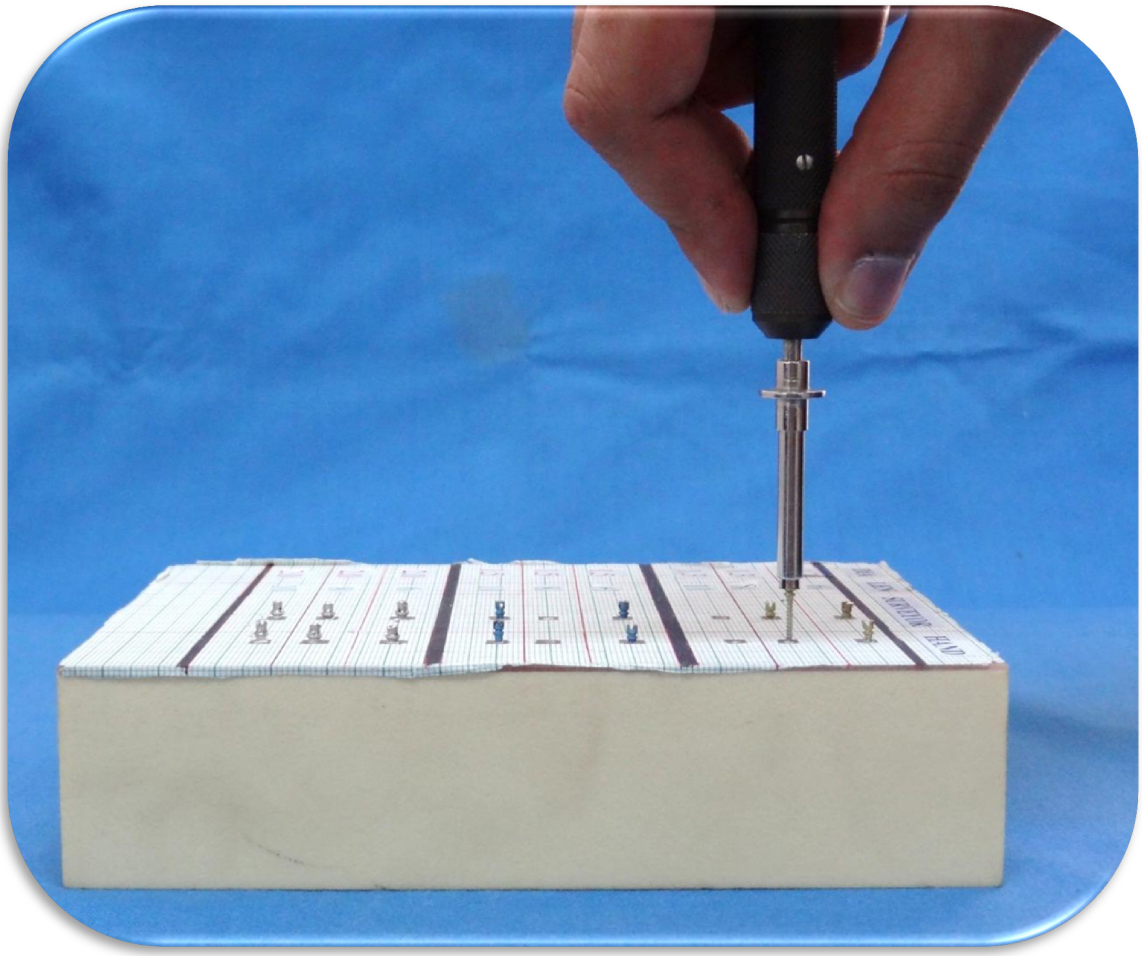
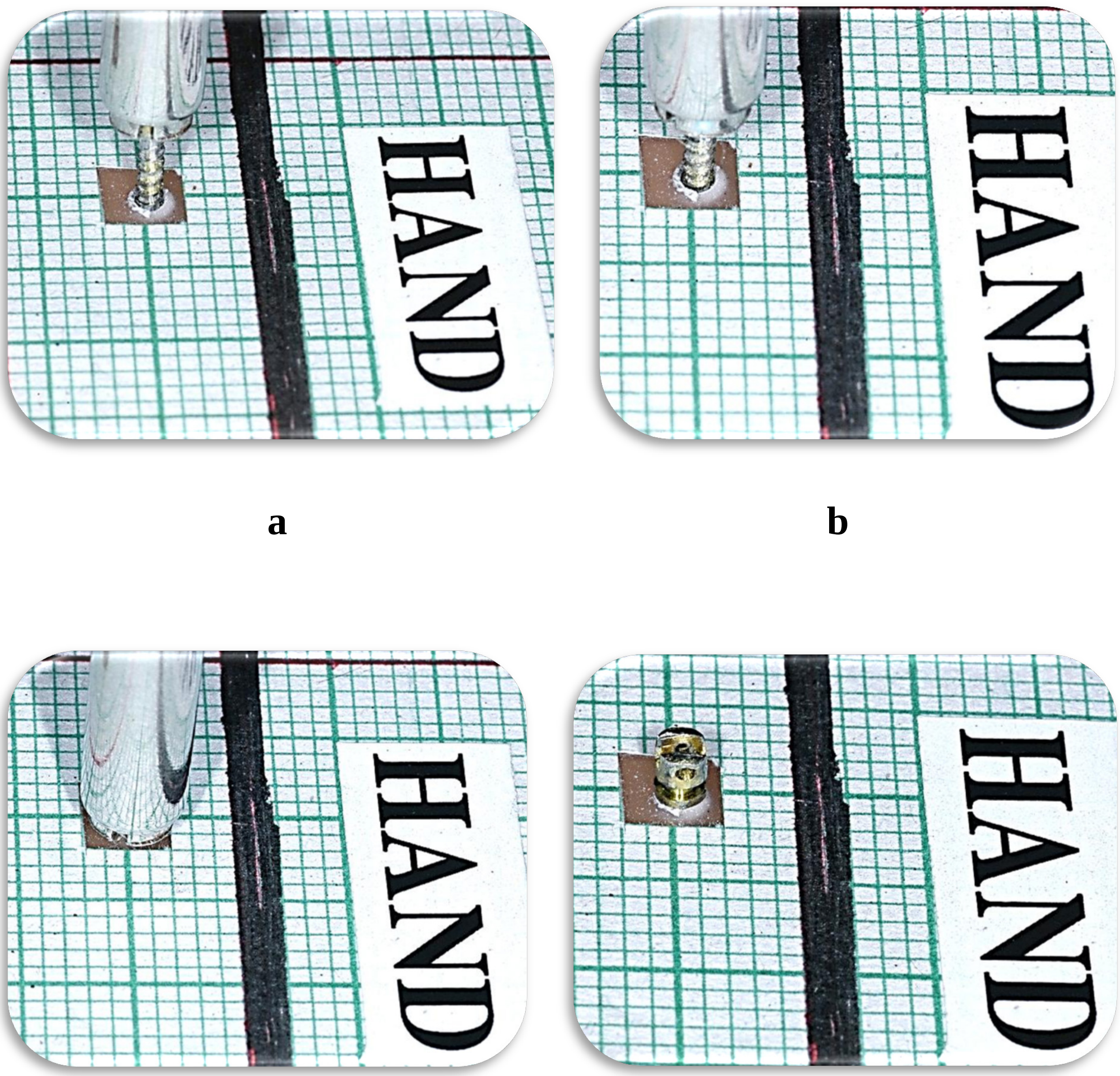


Figure 7: MSI Inserted With Free-Hand Method Without Guide



a **b**

c d

Figure 8: MSI Inserted In Homogenous Density Bone Blocks With Free-Hand Method Witthout Guide.

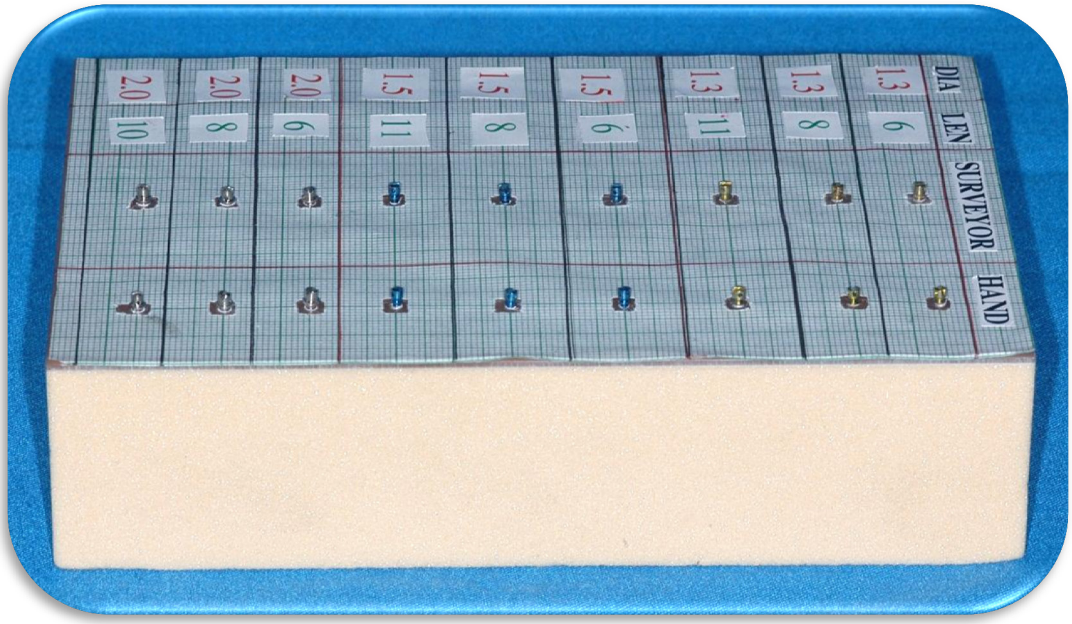


Figure 9: All MSI’s Inserted In Synthetic Bone Block.

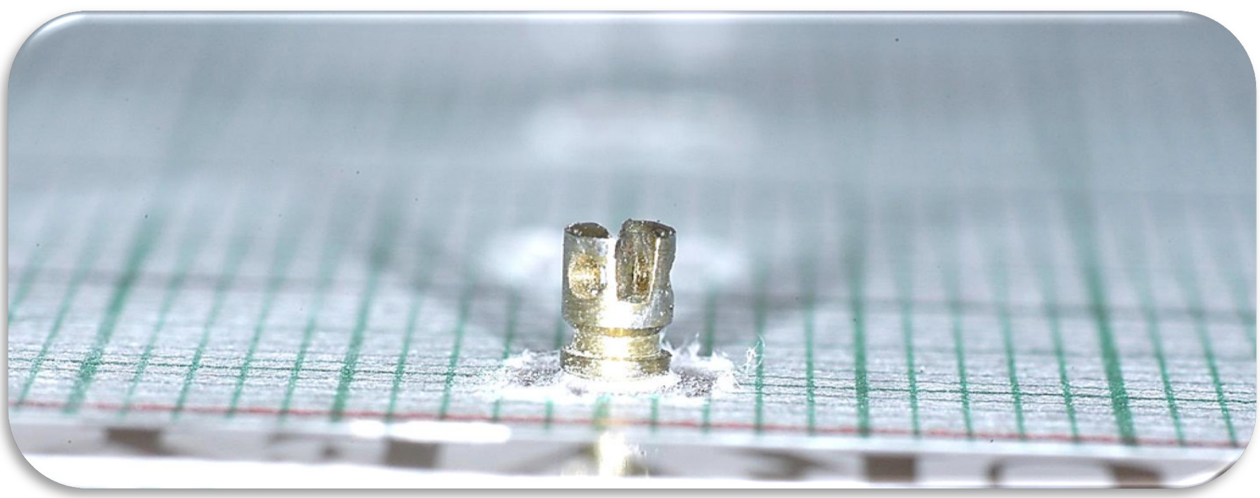


Figure 10: Head Of MSI In Contacting The Bone Surface.

Figure 11: Kodak 9500 Cone Beam Computed Tomography Scan Of Each Bone Block.

Figure 12: Positioning Of Bone Block With Median Beam Lines In CBCT Unit.

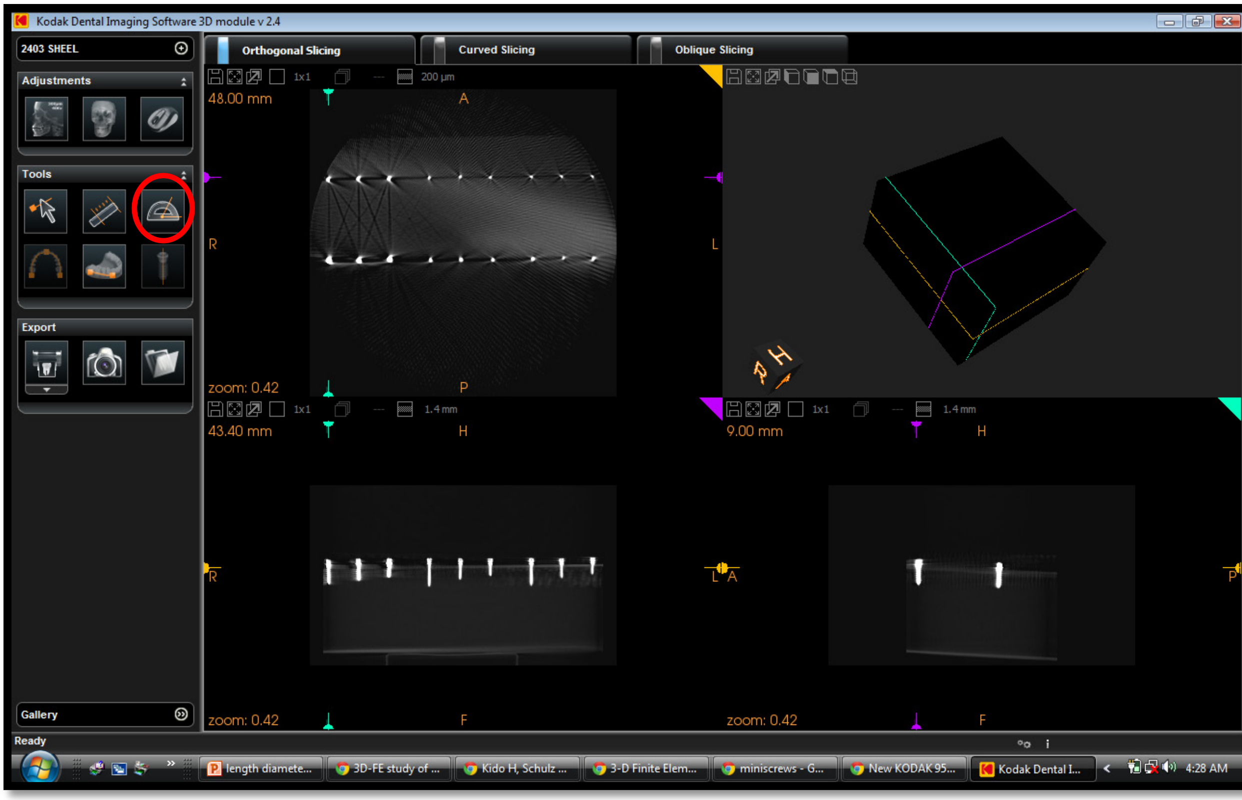


Figure 13: Image Of CBCT Scan With Angle Measuring Tools.

Figure 14: Mesio-Distal/Horizontal View (View 1) As Seen In Scan.

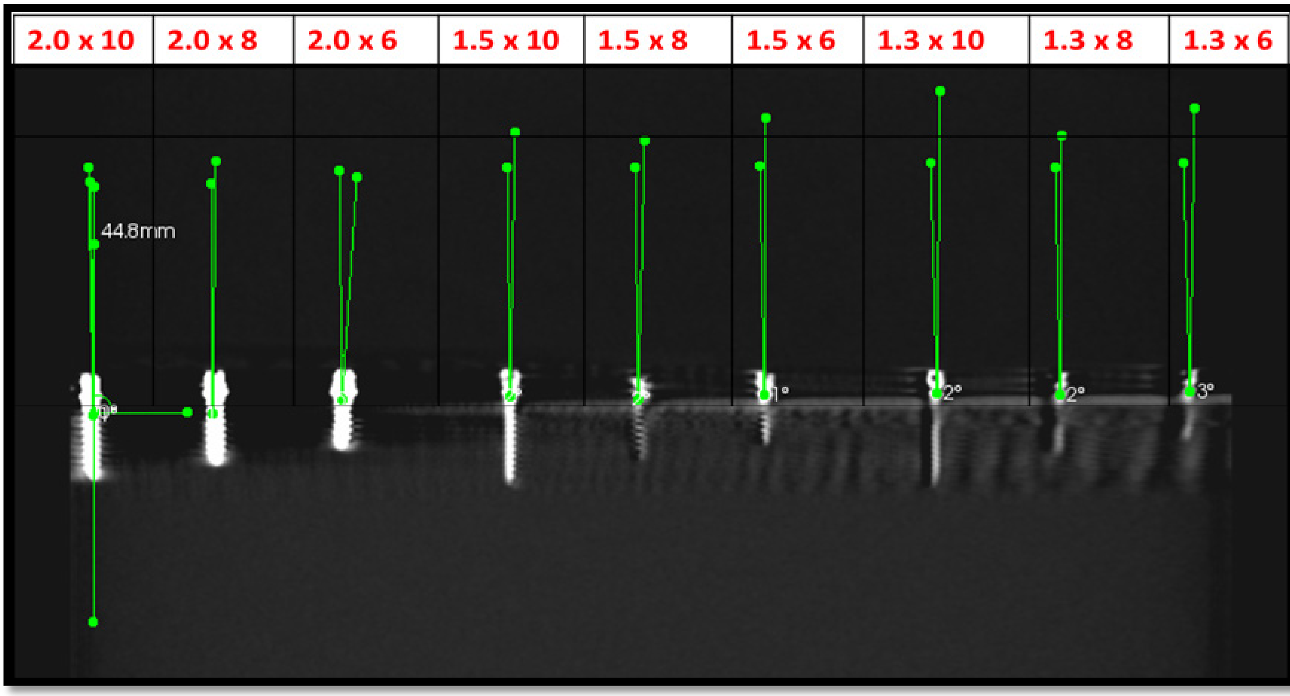


Figure 15: Angular Measurements In View 1.

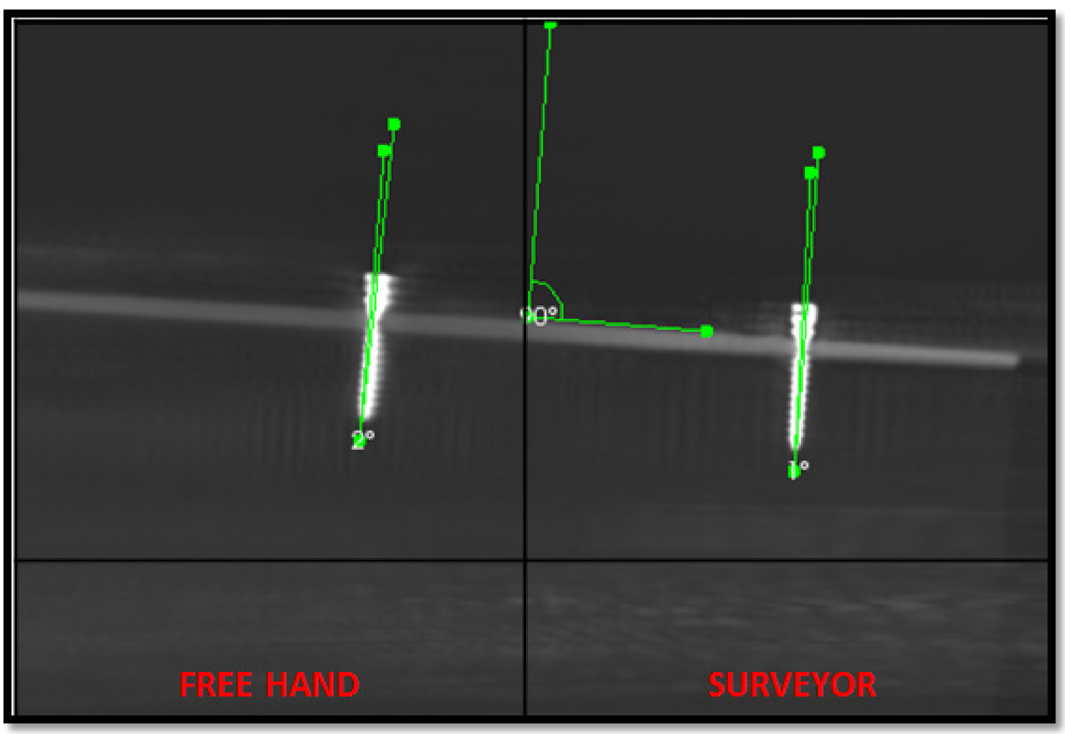


Figure 16: Angular Measurements In Vertical View (View 2).

RESULTS

I. <u>One Way ANOVA presented with 95% C.I</u>

- **For diameter (Table 5)**

In the mesio-distal plane (view 1) as diameter increases from 1.3mm, 1.5mm and 2mm the mean angular deviations also correspondingly increased from 1.64^0, 1.9^0 and 2.4^0 respectively with a significant P value (0.000). In the vertical plane (view 2) as diameter increases from 1.3mm, 1.5mm and 2mm the mean angular deviations also correspondingly increased from 1.4^0, 1.5^0 and 1.9^0respectively with a significant P value (0.000). Hence it can be safely concluded that angular deviation of MSI increases with increase in diameter of MSI.

- **For length (Table 6)**

In mesio-distal plane (view 1) as length increases from 6mm, 8mm and 10mm the mean angular deviations also correspondingly increased from 1.92^0, 1.97^0 and 2.1^0 respectively with a P value of .341 which is not considered statistically significant. In (view 2) as length increases from 6mm , 8mm and 10mm the mean angular deviations also correspondingly increased from 1.2^0, 1.7^0 and 1.8^0 respectively with a significant P value (0.000). Hence it can be concluded that angular deviation increases with increase in length of MSI in vertical plane (view 2).

- **For bone density (Table 7)**

In mesio-distal plane (view 1) as bone density increases from 10pcf, 20pcf and 30pcf the mean angular deviations also correspondingly increased from 1^0, 2.4^0 and 2.5^0 respectively. with a significant P value (0.000). In vertical plane (view 2) as bone density increases from 10pcf, 20pcf and 30pcf the mean angular deviations were 1.1^0, 1.9^0 and 1.7^0. View 2 has a P value of .000 showing high statistical significance. Hence, it can be concluded that angular deviations of MSI were maximum with 30pcf bone density in mesio-distal plane (view 1) and 20pcf in the vertical plane (view 2).

- **For method (Table 8)**

In mesio-distal plane (view 1) between hand and surveyor group mean angular deviations were 2.6^0 and 1.4^0 respectively. View 1 has a P value of .000 showing high statistical significance. In vertical plane (view 2) between the hand and surveyor group the mean angular deviation were 1.7^0 and 1.5^0 respectively. View 2 has a P value of .000 showing high statistical significance. Thus we conclude that angular deviations with free-hand MSI insertion were high compared to guided MSI insertion in both mesio-distal (view 1) and vertical plane (view 2).

II. <u>Cross Tabs with Chi Square</u>

- **For diameter (Table 9)**

In mesio-distal plane (view 1) it can be seen that as the diameter increases from 1.3mm , 1.5mm and 2mm the number of acceptable MSI placements in (view 1) were 107 (45%) , 52 (22%) and 77 (33.6%) respectively. Along with it the number of non-acceptable MSI placements were 73 (24%), 128 (42.1%) and 103 (33.9%) respectively. In vertical plane (view 2) that as the diameter increases from 1.3mm , 1.5mm and 2mm the number of acceptable MSI placements were 101 (38.4%) , 94 (35.7%) and 68 (25.9%) respectively. Along with it the number of non-acceptable MSI placements were 79 (28.5%), 86 (31%) and

112 (40.4%) respectively. (View 1) and (view 2) both had a P value of .000 and .001 respectively showing high statistical significance.

Hence we conclude that angular deviation was increased beyond 1^0 to make MSI placement non-acceptable most frequently with the 1.5mm diameter group as compared to 1.3mm and 2mm groups in mesio-distal plane (view 1) and with the 2 mm diameter group as compared to 1.3mm and 1.5mm groups in the vertical plane (view 2).

- **For length (Table 10)**

It can be seen that as the diameter increases from 6mm to 8mm to 10mm the number of acceptable MSI placements in (view 1) were 87 (36.9%) , 86 (36.4%) and 63 (26.7%) respectively. Along with it the number of non-acceptable MSI placements were 93 (30.6%), 94 (30.9%) and 117 (38.5%) respectively. In view 2 that as the diameter increases from 6mm , 8mm and 10mm the number of acceptable MSI placements were 123 (46.8%) , 69 (26.2%) and increases to 71 (27%) respectively. Along with it the number of non-acceptable MSI placements were 57 (20.6%), 111 (40.1%) and 109 (39.4%) respectively. (View 1) and (view 2) both had a P value of .016 and .000 respectively showing high statistical significance.

Hence we conclude that angular deviation was increased beyond 1^0 to make MSI placement non-acceptable most frequently with the 10mm length MSI as compared to 6mm and 8mm MSI length in mesio-distal plane (view 1) and with the 8mm length group as compared to 6mm and 10mm MSI length in the vertical plane (view 2).

- **For bone density (Table 11)**

It can be seen that as the bone density increases from 10pcf, 20pcf and 30pcf the number of acceptable MSI placements in (view 1) were 127 (53.8%), 54 (22.9%) and 55 (23.3%)

respectively. Along with it the number of non-acceptable MSI placements were 53 (17.4%), 126 (41.4%) and 125 (41.1%) respectively. In vertical plane (view 2) that as the bone density increases from 10pcf, 20pcf and 30pcf the number of acceptable MSI placements were 115 (43.7%), 83 (31.6%) and 65 (24.7%) respectively. Along with it the number of non-acceptable MSI placements were 65 (23.5%), 97 (35%) and 115 (41.5%) respectively. (View 1) and (view 2) both had a P value of .000 and .000 respectively showing high statistical significance.

Hence we conclude that angular deviation was increased beyond 1^0 to make MSI placement non-acceptable most frequently with the 20pcf group as compared to 10pcf and 30pcf groups in mesio-distal plane (view 1) and with the 30pcf group as compared to 10pcf and 20pcf groups in the vertical plane (view 2).

- **For method (Table 12)**

It can be seen that between hand and surveyor group the number of acceptable MSI placements in view 1 were 83 (35.2%) to 153 (64.8%) respectively. Along with it the number of non-acceptable MSI placements were 187 (61.5%) to 117 (38.5%) respectively. (View 1) had a P value of .000 showing high statistical significance. In vertical plane (view 2) between hand and surveyor MSI's the number of acceptable MSI placements were 133 (50.6%), 130 and (49.4%) respectively. Along with it the number of non-acceptable MSI placements were 137 (49.5%) to 140 (50.5%) respectively. This shows us that angular deviation was increased beyond 1^0 to make MSI placement non-acceptable most frequently with the surveyor MSI's as compared to hand MSI's in vertical plane (view 2). P value of view 2 was .796 and was not statistically significant.

Hence we conclude that angular deviation was increased beyond 1^0 to make MSI placement non-acceptable most frequently with the hand group as compared to surveyor group in the mesio-distal plane (view 1).

III. <u>Univariate logistic regression presented with Odd's ratio (Table 13)</u>

- In view 1:

For bone density odd's ratio of 8.635 for 20pcf and 8.383 for 30pcf shows that angular deviation was maximum with 20pcf deviation in mesio-distal plane (view1).

For method odd's ratio of 0.242 for surveyor MSI's shows that angular deviation is high in free hand placement MSI's in mesio-distal plane (view 1).

For length odd's ratio of 2.13 for 10mm shows that angular deviation increases with increase in length of MSI in mesio-distal plane (view 1).

For diameter odd's ratio of 5.426 for 1.5mm and 2.486 for 2mm shows that angular deviation is maximum in 1.5mm diameter MSI's in mesio-distal plane.(view 1)

- In view 2:

For bone density odd's ratio of 2.266 for 20pcf and 3.608 for 30pcf shows that angular deviation increases with increase in bone density in vertical plane (view 2).

For method odd's ratio of 1.504 for surveyor MSI's is not significant as P value is 0.779.

For length odd's ratio of 3.932 for 8mm and 3.737 for 10mm shows that angular deviation is maximum with 8mm MSI in vertical plane (view 2).

For diameter odd's ratio of 2.365 for 2mm shows that angular deviation is maximum in 2mm diameter MSI's in vertical plane (view 2).

Hence we conclude that odd's ratio was maximum for bone density as compared to length of MSI, diameter of MSI and method of insertion of MSI.

Angular deviations for each MSI with respect to length, diameter, bone density and method of insertion are given in descriptive statistics table 3 and table 4.

Tables & Graphs

Table 1- Mechanical properties of synthetic bone block

DENSITY		COMPRESSIVE		TENSILE		SHEAR	
		STRENGTH	MODULUS	STRENGTH	MODULUS	STRENGTH	MODULUS
Pcf	g/cc	MPa	Mpa	Mpa	Mpa	Mpa	Mpa
10*	0.2	2.2	58	2.1	86	1.6	19
20*	0.3	8.4	210	5.6	284	4.3	49
30*	0.5	18	445	12	592	7.6	87

Table 2- Mechanical properties of epoxy sheet

DENSITY g/cc	LONGITUDINAL TENSILE		COMPRESSIVE	
	STRENGTH	MODULUS	STRENGTH	MODULUS
	Mpa	Gpa	Mpa	Gpa
1.64	106	16	157	16.7
	TRANSVERSE TENSILE			
	STRENGTH	MODULUS		
	MPa	GPa		
	93	10		

Table 3- Descriptive statistics of MSI inserted by surveyor method (Guide)

method	bone	length	diameter	view1	V1 std.dev	view2	V2 std.dev
Surveyor	Total	6	1.3	0.6333	0.76489	0.8333	1.01992
			1.5	1.5	0.68229	1.0333	0.49013
			2	1.9667	1.95613	1.7333	1.33735
			Total	1.3667	1.37759	1.2	1.07264
		8	1.3	0.6667	0.7581	1.1	1.12495
			1.5	0.8333	0.79148	1.9	0.54772
			2	1.8333	1.34121	2.1667	0.79148
			Total	1.1111	1.11622	1.7222	0.96019
		10	1.3	0.6667	0.66089	1.3	1.20773
			1.5	2.6	0.81368	1.8333	0.74664
			2	2	1.28654	1.7	1.317
			Total	1.7556	1.24802	1.6111	1.12873
		Total	1.3	0.6556	0.72144	1.0778	1.12408
			1.5	1.6444	1.05267	1.5889	0.71727
			2	1.9333	1.54192	1.8667	1.18227
			Total	1.4111	1.27511	1.5111	1.07604

Table 4- Descriptive statistics of MSI inserted by free-hand method

method	bone	length	diameter	view1	V1 std.dev	view2	V2 std.dev
HAND	Total	6	1.3	2.4	2.28337	1.7667	1.25075
			1.5	2.7	0.65126	1.1	1.24152
			2	2.3333	2.65659	1.1	0.84486
			Total	2.4778	2.0402	1.3222	1.1595
		8	1.3	3.0333	1.58622	1.6667	0.84418
			1.5	1.9	1.09387	1.7667	0.8172
			2	3.6	2.62087	1.9333	0.98027
			Total	2.8444	1.98823	1.7889	0.88043
		10	1.3	2.4667	1.19578	1.8333	0.64772
			1.5	2.2333	0.72793	1.7	1.60065
			2	3.0667	1.98152	2.8333	1.96668
			Total	2.5889	1.42919	2.1222	1.57814
		Total	1.3	2.6333	1.75108	1.7556	0.93989
			1.5	2.2778	0.89978	1.5222	1.2828
			2	3	2.46777	1.9556	1.52073

Table 5- Descriptives Statistics of various diameters

		N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		SIGNIFICANCE (P)
						Lower Bound	Upper Bound	
View1	1.3	180	1.6444	1.66335	0.12398	1.3998	1.8891	0
	1.5	180	1.9611	1.02681	0.07653	1.8101	2.1121	
	2	180	2.4667	2.1204	0.15805	2.1548	2.7785	
view2	1.3	180	1.4167	1.08764	0.08107	1.2567	1.5766	
	1.5	180	1.5556	1.03687	0.07728	1.4031	1.7081	
	2	180	1.9111	1.35897	0.10129	1.7112	2.111	0

P Value < 0.05 Is Considered Statistically Significant

Table 6- Descriptives Statistics of various lengths

		N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		SIGNIFICANCE (P)
						Lower Bound	Upper Bound	
View1	6	180	1.9222	1.82305	0.13588	1.6541	2.1904	0.341
	8	180	1.9778	1.82764	0.13622	1.709	2.2466	
	10	180	2.1722	1.40164	0.10447	1.9661	2.3784	
view2	6	180	1.2611	1.11548	0.08314	1.097	1.4252	0
	8	180	1.7556	0.91921	0.06851	1.6204	1.8908	
	10	180	1.8667	1.39192	0.10375	1.6619	2.0714	

P Value < 0.05 Is Considered Statistically Significant

Table 7- Descriptives Statistics of various bone densities

		N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		SIGNIFICANCE (P)
						Lower Bound	Upper Bound	
View1	10	180	1.0222	0.97428	0.07262	0.8789	1.1655	0
	20	180	2.4556	1.49234	0.11123	2.2361	2.6751	
	30	180	2.5944	1.99075	0.14838	2.3016	2.8872	
view2	10	180	1.15	1.07003	0.07976	0.9926	1.3074	0
	20	180	1.9444	1.31482	0.098	1.7511	2.1378	
	30	180	1.7889	1.00273	0.07474	1.6414	1.9364	

P Value < 0.05 Is Considered Statistically Significant

Table 8- Descriptives Statistics of MSI placement methods

		N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		SIGNIFICANCE (P)
						Lower Bound	Upper Bound	
View1	Hand	270	2.637	1.8397	0.11196	2.4166	2.8575	0
	Surveyor	270	1.4111	1.27511	0.0776	1.2583	1.5639	
view2	Hand	270	1.7444	1.27802	0.07778	1.5913	1.8976	0.796
	Surveyor	270	1.5111	1.07604	0.06549	1.3822	1.64	

P Value < 0.05 Is Considered Statistically Significant

Table 9 - Comparison of acceptable and non-acceptable MSI deviations with increase in diameter

		VIEW 1				P VALUE (CHI SQUARE)	VIEW 2				P VALUE (CHI SQUARE)
		ACCEPTABLE		NON-ACCEPTABLE			ACCEPTABLE		NON-ACCEPTABLE		
		N	%	N	%		N	%	N	%	
DIAMETER	1.3	107	45.3	73	24	0	101	38.4	79	28.5	0.001
	1.5	52	22	128	42.1		94	35.7	86	31	
	2	77	32.6	103	33.9		68	25.9	112	40.4	

P Value < 0.05 Is Considered Statistically Significant

Table 10 -Comparison of acceptable and non-acceptable MSI deviations with increase in lenghts

		VIEW 1				P VALUE (CHI SQUARE)	VIEW 2				P VALUE (CHI SQUARE)
		ACCEPTABLE		NON-ACCEPTABLE			ACCEPTABLE		NON-ACCEPTABLE		
		N	%	N	%		N	%	N	%	
LENGTH	6	87	36.9	93	30.6	0.016	123	46.8	57	20.6	0
	8	86	36.4	94	30.9		69	26.2	111	40.1	
	10	63	26.7	117	38.5		71	27	109	39.4	

P Value < 0.05 Is Considered Statistically Significant

Table 11-Comparison of acceptable and non-acceptable MSI deviations with increase in bone densities

		VIEW 1				P VALUE (CHI SQUARE)	VIEW 2				P VALUE (CHI SQUARE)
		ACCEPTABLE		NON-ACCEPTABLE			ACCEPTABLE		NON-ACCEPTABLE		
		N	%	N	%		N	%	N	%	
BONE DENSITY	10	127	53.8	53	17.4	0	115	43.7	65	23.5	0
	20	54	22.9	126	41.4		83	31.6	97	35	
	30	55	23.3	125	41.1		65	24.7	115	41.5	

P Value < 0.05 Is Considered Statistically Significant

Table 12-Comparision of acceptable and non-acceptable MSI deviation with MSI insertion methods

		VIEW 1				P VALUE (CHI SQUARE)	VIEW 2				P VALUE (CHI SQUARE)
		ACCEPTABLE		NON-ACCEPTABLE			ACCEPTABLE		NON-ACCEPTABLE		
		N	%	N	%		N	%	N	%	
METHOD	HAND	83	35.2	187	61.5	0	133	50.6	137	49.5	0
	SURVEYOR	153	64.8	117	38.5		130	49.4	140	50.5	

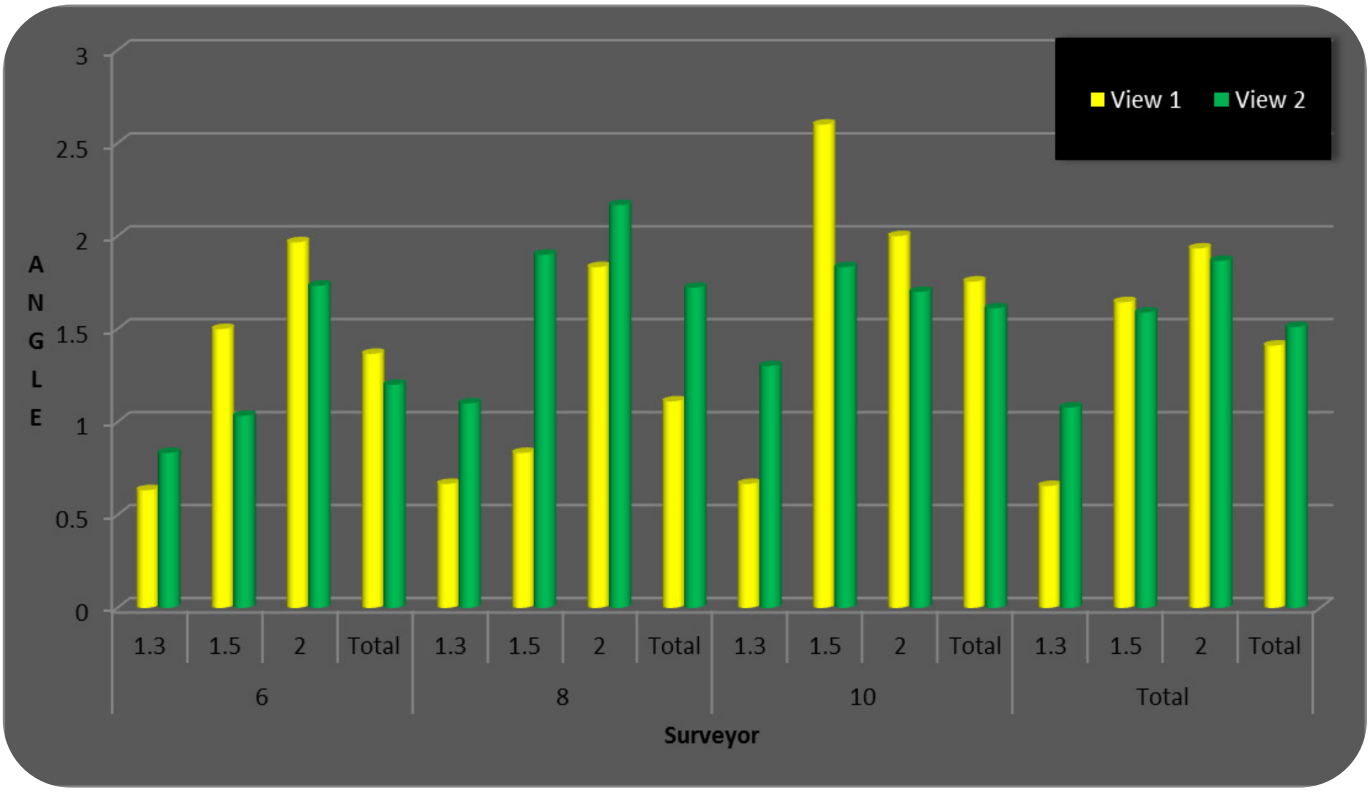
P Value < 0.05 Is Considered Statistically Significant

Table 13-Tabulation of the major factors causing angular deviation

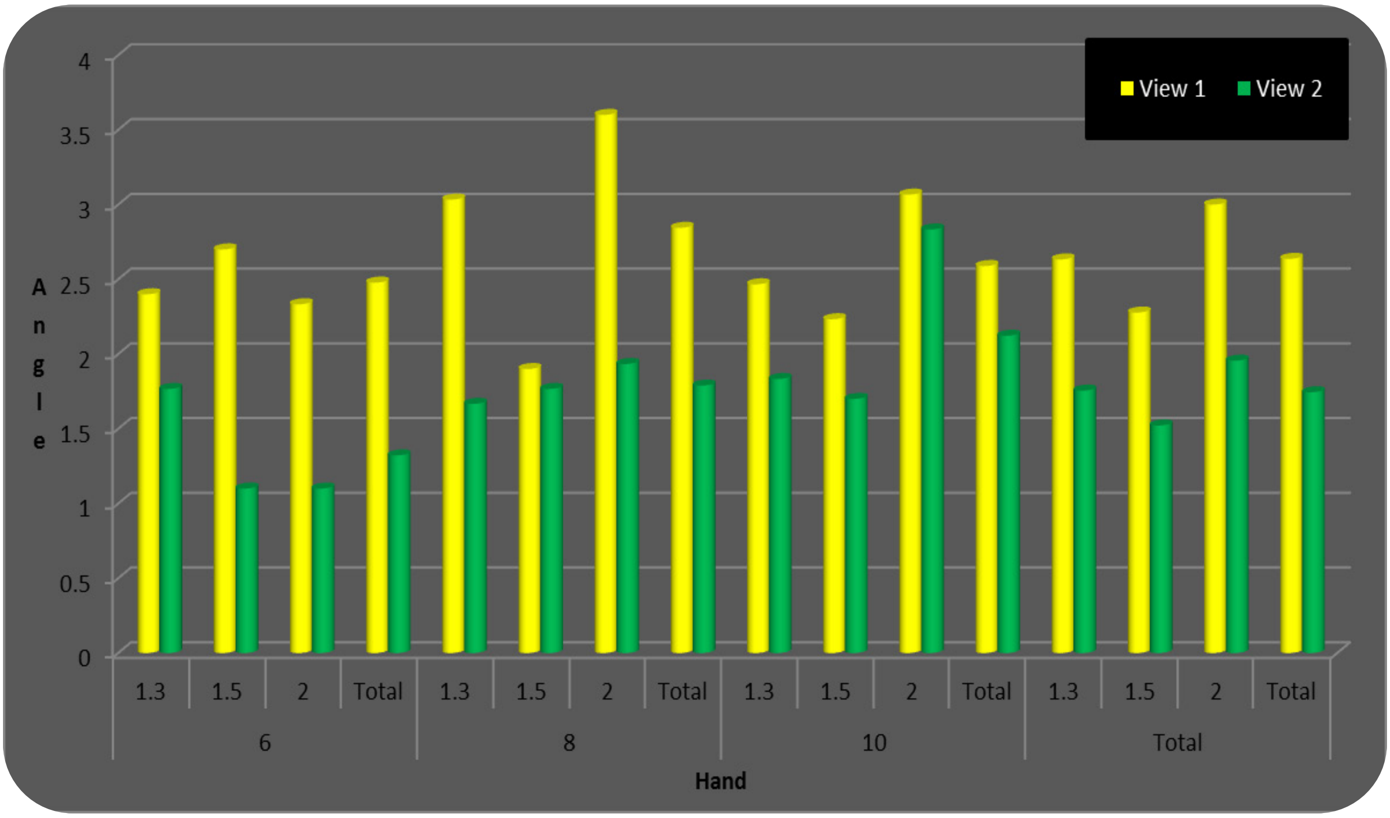
		View 1				View 2			
		Odd's Ratio	95.0% C.I .for OR		Sig.	Odd's Ratio	95.0% C.I. for OR		Sig.
			Lower	Upper			Lower	Upper	
Bone	10	Reference				Reference			
	20	8.635	5.095	14.634	0	2.266	1.445	3.552	0
	30	8.383	4.953	14.187	0	3.608	2.277	5.719	0
Method	hand	Reference				Reference			
	Surveyor	0.242	0.159	0.368	0	1.054	0.73	1.522	0.779
Length	6 mm	Reference				Reference			
	8 mm	1.032	0.632	1.683	0.901	3.932	2.483	6.227	0
	10 mm	2.13	1.293	3.508	0.003	3.737	2.363	5.91	0
Diameter	1.3	Reference				Reference			
	1.5	5.426	3.228	9.121	0	1.199	0.767	1.874	0.426
	2	2.486	1.519	4.067	0	2.365	1.5	3.729	0

P Value < 0.05 Is Considered Statistically Significant

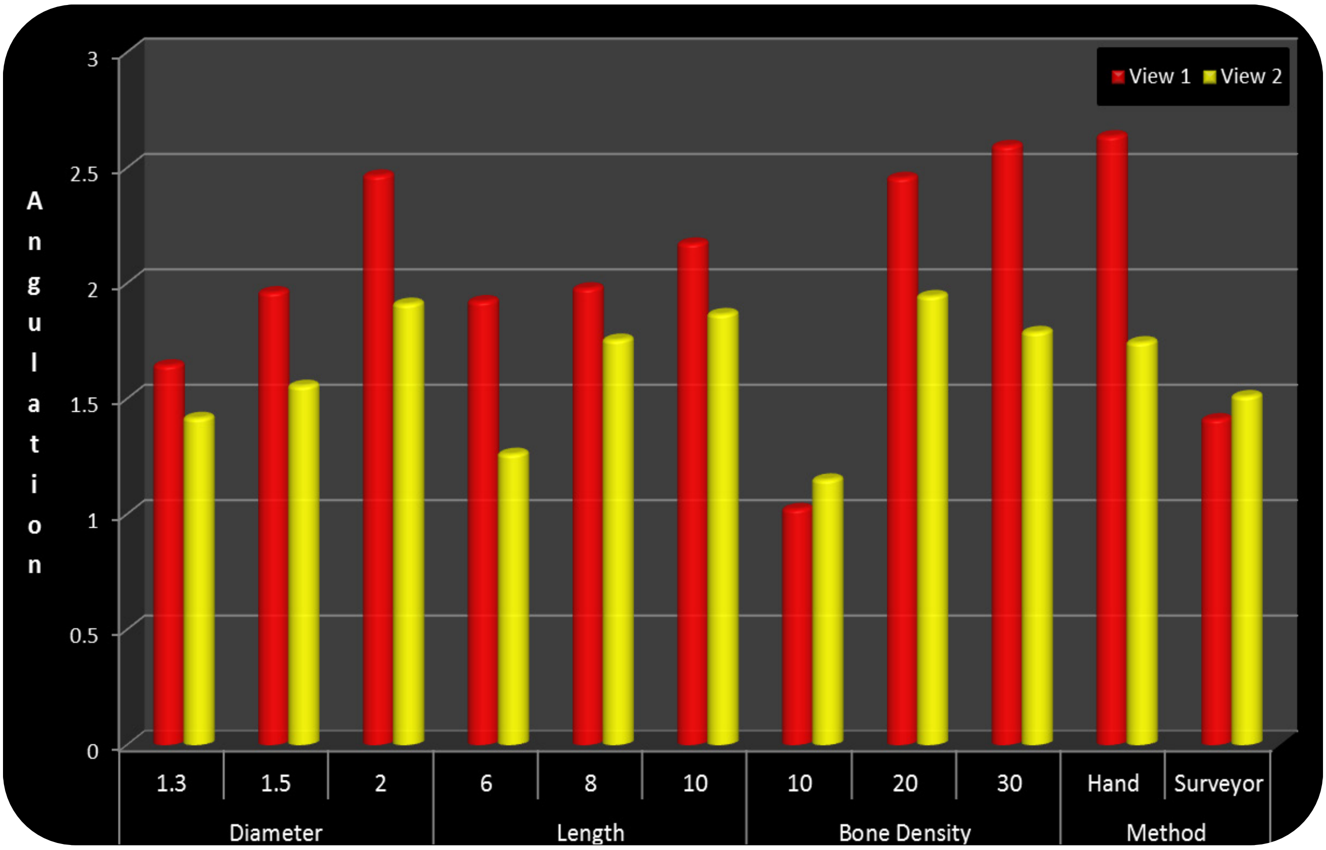
Graph 1 – Descriptive Statics of Length and Diameter of MSI by Surveyor



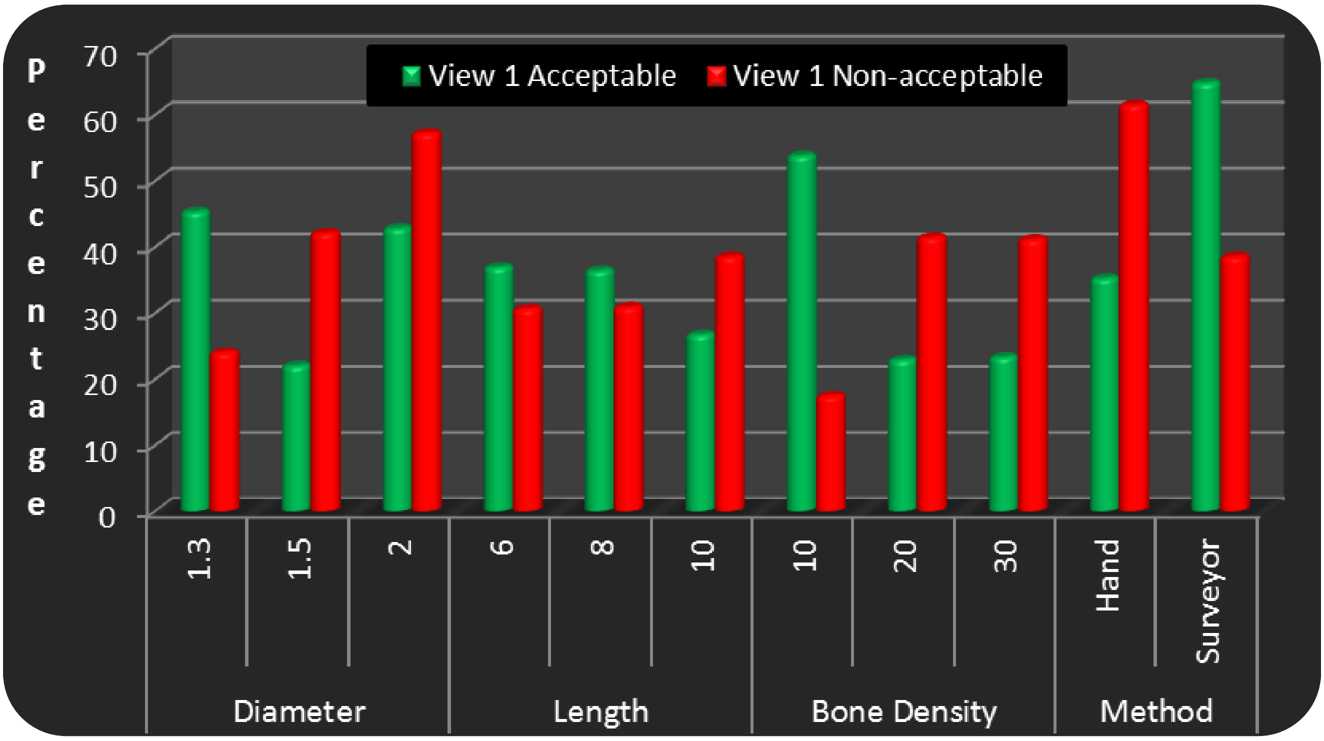
Graph 2 – Descriptive Statics of Length and Diameter of MSI by Hand



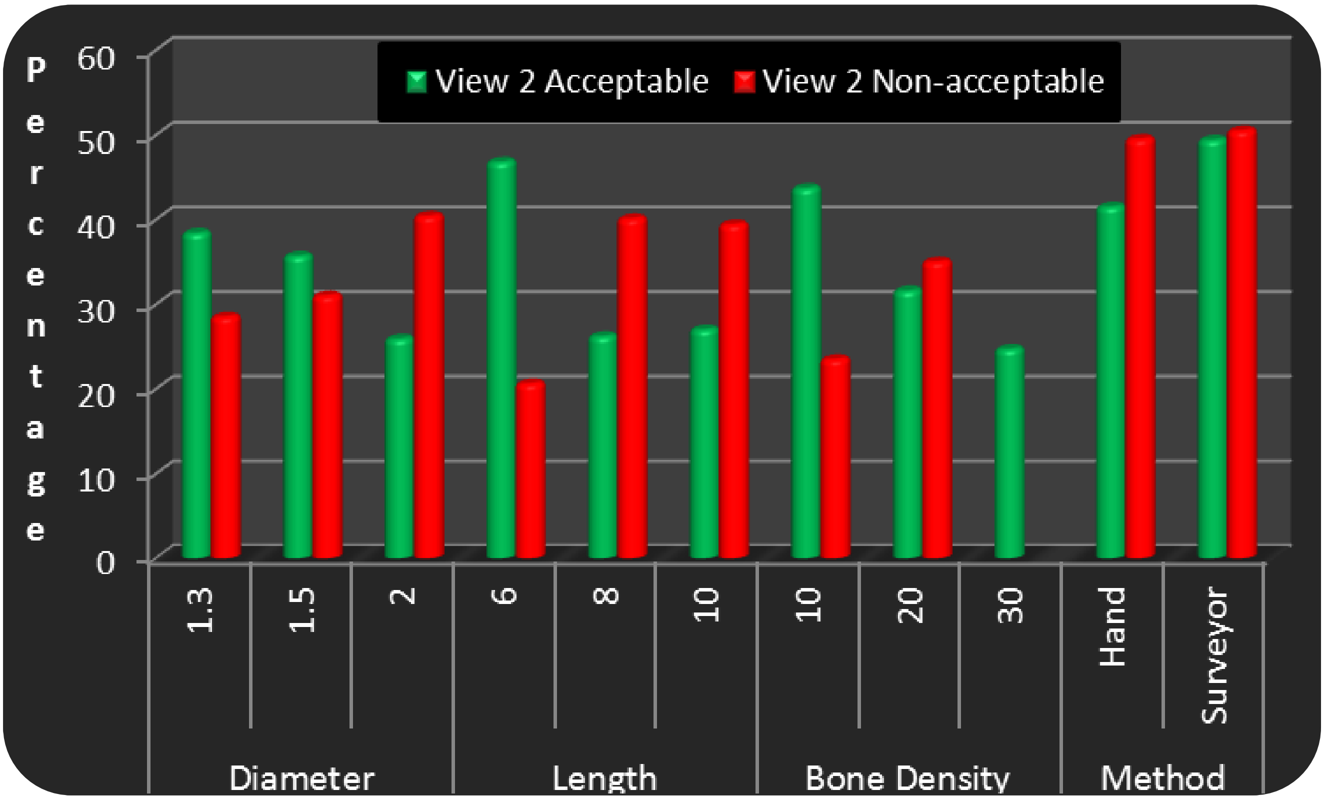
Graph 3 – Comparison of All Factors in Mesiodistal/Horizontal (View 1) and Vertical (View 2)



Graph 4 – Comparison of Number of Acceptable and Non-acceptable MSI Placements in View 1



Graph 5 – Comparison of Number of Acceptable and Non-acceptable MSI Placements in View 2



DISCUSSION

This experimental study was done to evaluate the angular deviation of MSI and identify the factors that can have a significant influence on the precise placement of MSI using a 3D cone beam computed tomography. Numerous anatomical sites for MSI insertion have been presented in the maxilla and mandible.[6,53,65,101,102,103,106,109,116,119,143] The inter-radicular septum is considered as one of the most commonly used locations for MSI placement. Precise placement of MSI in the inter-radicular septum is important to achieve safety of the vital structure and stability.[22,27] Even minor angular deviation in the trajectory during placement of MSI increases the risks of root injury and damage to vital structure in the oral cavity. **Kuroda et al**[66] showed that root proximity is a major factor for MSI failure. Their results demonstrated a significant correlation between late stability and clearance of the MSI. Complication of root damage during MSI insertion can range from slight root contact causing screw failure to extreme root perforation causing pulp damage.

Therefore, this study focused on factors causing angular deviation of MSI and measures to be taken to prevent complications of MSI, and increase the success rate of this anchorage system.

Some of these factors tested in this study were MSI related (various diameter and length of the MSI), bone related (quality and quantity of bone), and operated related (MSI placement using a guide and freehand MSI placement). The exact role of these factors, on the angular deviation of MSI has not been studied previously.

The densities of the synthetic bone selected for this study were chosen to control the variability of bone properties found in natural bone.[56,76,125] Sawbones with homogeneous density in each block was used which is an equivalent for jaw bone, (Sawbones; Pacific

Research Laboratories Inc., Washington, USA). Cortical bone thickness (CBT) of 1 mm was used in this study, which is similar to the buccal cortical thickness in anatomic regions of the human maxilla and mandible.[33,75,93,95,105,125]

Various lengths and diameters of MSI were first inserted using the surveyor, to maintain the perpendicular path of insertion. Next all the MSIs were inserted by the free-hand method. Each bone block was scanned by Kodak 9500 cone beam computed tomography machine and Kodak Dental Imaging Software 3D Module Version 2.4 was used to measure the angular deviations in the horizontal plane (view1) and vertical plane (view2). Each measurement was recorded and repeated after a 2 day interval to reduce the operator bias for measurements.

<u>Diameter:</u>

Miyawaki et al[88] showed that diameter of the MSI is significantly associated with its stability. They found MSI with 1mm diameter is at risk of more failure and 0 % success rate. However, the 1.2 mm, 1.3 mm and 1.5 mm diameter MSI had higher success rates than the 1.6 mm MSI. Though thinner MSI's are easier to place in most inter-dental locations, the drawback of thinner MSI's is the greater potential for screw fracture. **Kuroda et al**[66] also agrees with the findings that smaller MSIs tend to break during placement and removal.

The external diameter of the threads of most MSI varies between 1.2mm and 2.3mm. The MSI must be of sufficient structural diameter to resist breakage under load, yet narrow enough to fit into typical inter-radicular spaces to prevent damage of vital structures. Safety is a major consideration for MSI placement in the bone and can be achieved by ensuring that the proposed MSI site has adequate interradicular space to accommodate the diameter of MSI, thereby avoiding any root damage.

To determine the ideal diameter of a MSI, a few studies assessed the inter-radicular spaces. **Liou et al**[78] recommended 2 mm of safety clearance between MSI and the dental root; thus, a 1.5mm diameter MSI would require 5.5mm of interradicular space width to ensure root integrity, making MSI placement impossible in most sites.

Schnelle et al[119] studied 60 panoramic radiographs with minimal radiographic distortion and complete eruption of permanent second molars of orthodontic patients. They measured inter-radicular sites with a digital caliper .They reported that three millimeters of bone stock existed primarily in the posterior regions mesial to the maxillary first molar and mesial and distal to the mandibular first molar and four mm of bone stock existed primarily mesial and distal to the mandibular first molar and hence considered 3 to 4 mm of inter-radicular distance as the minimum amount required for placing an MSI.

Poggio et al[108,109] studied volumetric tomographic images of 25 maxillae and 25 mandibles taken with the New Tom System T. For each inter-radicular space, the mesio-distal and the buccolingual distances were measured at two, five, eight, and 11mm from the alveolar crest. They considered that the width of periodontal ligament is approximately 0.25 mm, and assumed that a minimum clearance of 1mm of alveolar bone around the screw could be sufficient for periodontal health: combining this value with their study data and the screw diameter, the safer zones for screw insertion in the inter-radicular spaces were given by them. They emphasized combining inter-radicular space measurements with the MSI's diameter and bone clearance to protect periodontal health and ensure implant stability. They recommended inter-radicular spaces greater than 3.1 mm as safe zones for microimplants with diameters of 1.2 to 1.3 mm.

Maino et al[81,82], Ishii et al[50] and Miyawaki et al[88] in their respective studies also reported that if the inter-radicular septum is to be used for MSI placement, it should be at least 2.5-3mm wide, because the MSI will take up about half the inter-radicular space. **Park et al[105]** agrees with the above studies and reported that the diameter of the MSI is restricted by the available inter-radicular space and the recommended diameter of MSIs to be placed in inter-radicular spaces is 1.2 to 1.6 mm and because of great anatomic variations, it is important to evaluate the anatomy of the desired location for implant placement and consider different diameters of MSIs for each patient.

Since, the most frequent insertion site for MSI is between the roots of the adjacent teeth, the inter-radicular distance determines the minimum and maximum diameter of the MSI. The position of the teeth and their angulations both labio-lingually and mesio-distally determine the area of bone available between their roots where an MSI might be positioned. For the safe and effective retention of an MSI its length is rather secondary, the diameter is much more important.

Hence, this study was undertaken to determine angular deviation changes with respect to different diameter of MSI's.

From the results of the study (Table 5;Chart 1,2, 3)) the angular deviation of MSI in the horizontal plane (view 1) showed that as the diameter of MSI increases from 1.3mm, 1.5mm and 2mm the mean angular deviation also increased from 1.64^0, 1.9^0 and 2.4^0respectively. Similarly the vertical plane (view 2) showed that as the diameter increases from 1.3mm to 1.5mm and 2mm the mean angular deviation increases from 1.4^0, 1.5^0 and

1.9^0 respectively. Angular deviations were more in horizontal plane when compared with vertical plane. Hence, both in horizontal and vertical direction the angular deviation increases with increase in diameter and should be taken into consideration when selecting the MSI for any site. The probable reason could be because as the wider outer diameter of MSI increases, more bone is displaced during insertion, producing greater friction at the bone-screw interface, leading to increase angular deviations.

As the diameter of MSI increases from 1.3mm, 1.5mm and 2mm the non-acceptable angular deviations increases from the 24% to 42.1% and decreases to 33.9% in the mesio-distal plane. In the vertical plane 2mm MSI showed the maximum amount of non-acceptable deviations at 40.4% (Table 9; Chart 4). The number of non-acceptable deviations for 1.5mm and 1.3mm was also high at 31% and 28.5%. Hence, increase in diameter increases the angular deviation in both horizontal and vertical planes.

A study by **Moriyama et al**[91] simulating teeth in a typhodont and placing 1.8mm diameter MSI with a 3D guide showed that more mesio-distal deviations of MSI occur than vertical deviations in the freehand group and the values given by them were 7.49^0 +/- 6.09^0 and 6.31^0 +/- 3.82^0, respectively.

The results of our study with respect to increased diameter showed increased deviation in horizontal plane than vertical plane, which are in accordance with study by **Moriyama et al**[91]. However, in the study by Moriyama et al, there were several limitations. The fact that bone density was not considered as a major factor might have caused higher angular deviation values for them, than in our study.

Renjen R et al[112], in his study reported that in a clinical situation root damage is more likely to be inflicted by the threads of the MSI in an oblique manner rather than by the tip of the MSI, as would occur with a perpendicular placement path directed toward the root.

This proved that when examining on a radiograph it might seem that the tip of the MSI is not contacting the root but in reality the thread of the MSI could be causing root injury. Hence, chances of root damage increases with increase in diameter of MSI, as the threads of MSI are more close to the root surface.

Results of our study showed that 2mm diameter MSI caused maximum degree of angular deviation and precautions should be taken while using 2mm diameter MSI though they are not as frequently used as 1.3mm and 1.5mm diameter MSIs clinically.

Poggio et al[108,109] after studying the safe zone for MSI, also concluded that the diameter of MSI should not exceed 1.5mm which is in agreement with our findings. **Deguchi et al**[33], also agree in their 3D CT study that MSIs with diameters of 1.3 to 1.5mm are recommended for skeletal anchorage in inter-radicular areas.

Small increase in the outer diameter of MSI, greater than 1.5mm diameter, increases the chances of potential root contact.

Hence, apart from depending on the amount of inter-radicular space available, selecting appropriate diameter of MSI should be taken into consideration. This timely precaution will help avoid any injury to the roots of teeth and surrounding structures after MSI insertion.

Length:

According to **Park et al**[105], the mean alveolar process widths ranged in general from 4 to 6 mm; this suggests the ideal length of the MSI. But longer MSI are chosen in the maxilla than mandible to achieve more mechanical interlocking to compensate for the decreased bone density and hence, achieve more initial stability. It might seem logical that a longer MSI can provide greater stability because of a greater surface area contacting the bone, but MSI length is also related to the safety issue.

Lee et al[71] in their study reported that in terms of bucco-lingual thickness the only site that meets the requirement for MSI length, was between the first and second molars in the maxilla, showing as much as 5mm of mean safety depth. Since the depth of bone penetration might vary from 5mm to 7mm for most mono-cortical MSI's, the maxillary buccal intermolar region can be adequate for MSI of 5 to 7mm in length 7 and if longer MSI's are be placed they should be adequately angulated.

Tseng et al[132] found the length of the inserted MSI to be an important risk factor. These authors emphasized that the actual depth of insertion of MSI was more important than its length; they recommended length being at least 6 mm. **Deguchi et al**[33] also agree in their 3D CT study that MSIs with lengths of 6 to 8mm are recommended for skeletal anchorage in inter-radicular areas.

Park et al[105] in their study also showed simulation of various lengths of MSIs (6mm, 8mm and 10mm) and placement angulations (0^0 and 15^0)and reported that even a slight error in the placement angulation can damage the roots, especially with longer implants. Hence, they suggested that for the reasons of both stability and safety, it might not be advisable to use a MSI longer than 6 to 7 mm.

Park et al[101,] studied implant-related factors (type, length, and diameter) and reported that they did not show any statistically significant differences in success rates among them. The short screws they used for the fixation in the study did not jeopardize their performance.

Estelita et al[38,39] reported that for every degree of variation from the ideal penetration angle, at a depth of8mm, the tip of the surgical drill will deviate about.13mm. In other words, if the drill penetration angle is only 8° from ideal, the tip will deviate about 1.04mm. They said that in the narrow inter-radicular septum, even a minor error can result in root damage and exposure of root dentin can cause inflammation and root resorption, which can be exacerbated by orthodontic tooth movement. Hence it can be seen that with such small margin of error the most common causes of root damage from MSI insertion are improper site selection and an inaccurate angle of drill penetration with longer MSIs.

As short and small screws have less mechanical inter-digitation to the bone than do long and large screws, authors have recommended use of longer MSI. Also enough bucco-lingual width is not present to use longer MSI and few authors **(Lee et al**[71]**)** have recommended to angulate MSI for mechanical retention. However, according to **Mah et al**[80], MSIs should be placed at an angle of no more than 10° from perpendicular to the bone surface.

As it is impossible to place a MSI in an absolutely straight path without having minor deviation even after the use of 3D guided stent, hence this study undertaken to determine whether changes in length of MSI causes changes in degree of angular deviation of MSI.

The results of our study(Table 6;Chart 1,2,3) showed that as length increases from 6mm to 8mm and 10mm the mean angular deviation increases from 1.2^0 to 1.7^0 to 1.8^0 respectively in the vertical plane (view 2). In our study the number of non-acceptable angular deviations increases from 30.6% in 6mm group to 30.9% in 8mm group and 38.5% in 10mm group in the mesio-distal (view 1) plane.(Table 10;Chart 4) In the vertical plane the maximum numbers of unacceptable deviations were seen with the 8mm length MSI. This shows that even after perpendicular path of MSI insertion, angular deviation takes place. The degree of angular deviation will be more with increase in length of MSI, which will further increase the risk of root damage and other vital structures.

Kim et al[60] in his study used 8.5mm length MSI in the middle of the surgical site to asses MSI and root proximity using CBCT. They reported that to avoid root contact the clinician becomes so focused on the horizontal vector and compromise the vertical angulation during MSI placement without realizing the potential of maxillary sinus perforation. It was also said in this study that the vertical angulation of MSI placement has a significantly greater variability than the horizontal angulation. A dramatic difference on the vertical placement plane that tended to be inclined towards the long axis of teeth on the frontal CBCT plane was reported. They noted that the vertical placement angle of the right side was much more vertical to the surface of bone compared with the left side, which was most likely the result of greater right handed prevalence of clinicians placing MSI more inclined towards the patient's left side.

This further underlines the importance of the results from this study in the vertical plane. As the angular deviation increases in vertical plane with increase in length, even a small deviation at the tip in anatomical complex areas such as maxillary posterior region, where the sinus is close to the roots, can cause injury. So, if we consider the angulated placement of long MSI in regions such as the posterior maxillary region the risk of perforating the sinus and root injury increase considerably.

Also, when inter-radicular space is too narrow, teeth have dilacerated roots, the maxillary sinus is expanded, or there is severe alveolar bone loss, these might prohibit placement of longer length of MSI. Thus, MSI length should be chosen carefully in anatomically compromised sites.

Bone Density:

The host factors are related to quality and quantity of the bone. Both bone quality and quantity appear to be critical for successful placement of a MSI.[23] Bone quality (density) surrounding the MSI has an impact on implant stability[23,100,101]. However, bone densities vary from different subjects, as well as from different sites within the same subject, regardless of age, sex, and race. Human cadaver and animal bones were not chosen for this study to avoid natural variations in bone density.

Synthetic bone has been shown to be a good substitute for real bone.[56] Synthetic bone, which is commonly used when evaluating MSI, makes it possible to control the variability of natural bone properties[76,125.] The densities of the artificial bone selected for this study were chosen to represent human maxilla and mandible. Because natural bone density varies by jaw and area, this study was done using known measurements of bone density, which would provide practical information on the angular deviation of MSI.

Hence, this study was undertaken to determine the effects of varying bone density on angular deviation of MSI.

From the results of the study (Table 7; Chart1, 2, 3), in horizontal plane (view 1) as bone density increases from 10pcf, 20pcf and 30pcf the mean angular deviation increases from 1^0, 2.4^0 and 2.5^0 respectively. This shows us that as bone density increases angular deviation increases in mesio-distal direction (View 1). In vertical plane (View 2) as bone density increases from 10pcf, 20pcf and 30pcf the mean angular deviation increases from 1.1^0, 1.9^0 and then decreases to 1.7^0 respectively. This shows us that maximum amount of deviation occurred in 20pcf in vertical plane (View 2). Hence we can conclude that 20pcf bone density has higher degree of angular deviation in both horizontal and vertical planes compared to 10pcf and 30 pcf. The probable reason is that, greater bone density implies greater bone quantity, which requires higher torsional forces to advance MSI during insertion, which might result in increased angular deviation.

From the results, it can be seen that maximum number of non-acceptable placements are seen in 20pcf and 30pcf (difference of only 1 between the two) in the mesio-distal plane. In the vertical plane the maximum non-acceptable placements are seen with the 30pcf (41.5%). These results indicate that with increase in density we have increase in angular deviation beyond acceptable limits in both the planes, horizontal and vertical.. Also, free hand placement shows increased angular deviations when compared to surveyor guided insertion with increase in bone density.

Hence, density of bone at the MSI placement should be given due consideration before selecting MSI.

Choi et al[23] said a note should be taken that bone density tended to decrease with increasing depth, particularly in the posterior area. Mean bone density showed a progressive increase from the posterior to the anterior. This study also suggests that bone density increases with decreasing inter-radicular distance. This is supported by **Parfitt**[99], who examined normal variations in alveolar bone trabeculation.

In our opinion, there is yet another possible confounding variable which needs to be addressed. Literature states that; the density of the bone decreases as we move in from the buccal or lingual cortical plates towards the centre of the bony trough.[23] With an available outer limit of approximately 7mm between buccal and lingual plates; the use of an MSI of greater length is precluded. During the insertion procedure; the MSI would move from a region of high bone density (from one cortical plate) to a lower density region (bony trough). When a longer MSI is inserted deeper it would however be met once again with higher bone density as it approaches the opposite plate.

So hypothesizing, in a decreased inter-radicular space, we can expect a higher bone density and hence a higher deviation of the MSI in this region and adequate precaution should be taken to avoid injuring roots of teeth and other vital structures.

Park et al[105] in their study described that although 2 cortical bones can have the same thickness, they might have completely different bone mineral densities and hence different initial stability values. Hence density of cortical bone becomes an important factor. In our study since we used a uniform thickness of 1mm and density of 1.64g/cc to mimic the cortical bone the results describe variations in angular deviation with varying cancellous bone density.

Hence the results suggest that the differences in bone density according to depth and area should be considered when selecting and placing MSI for orthodontic anchorage.

In this study different bone densities were chosen as a significant variable, the impact of the variables on the regression equation was higher than those of MSI diameter, MSI length and placement methods. These results suggest that bone density play a major role in increasing angular deviation of MSI.

In situations where bone thickness and root proximity have the same characteristics between sites, site specific modification of interradicular level apical to the alveolar crest and adjustment of site after considering bone density may be helpful when placing a MSI safely .

While the synthetic bone used in the present study is well suited for controlling extraneous factors and focusing on the effects under consideration, but angular deviation of MSI in actual bone might show much more variable and might be expected to produce different magnitudes of difference.

Kau et al[54] in their study showed that when evaluating the placement of MSI's on average 65.7% of the roots were in contact with the PDL space in both maxilla and mandible. These results indicate that every 2 out of 3 MSI's had contact of PDL. The numbers from 3D CBCT imaging show a far higher number of contact to PDL than reported with traditional 2 dimensional radiographs.[44,60,75,94,112] It is not yet clear whether apical positioning or an angulated placement path can reliably prevent root damage regardless of the region in the arch. If the MSI placement is technique sensitive because of complex anatomy, such as expanded sinus or alveolar bone loss, a precise surgical guide fabricated by using CBCT data should be used.[54]

Miniscrew Implant Placement Methods:

There are 2 methods of MSI insertion: MSIs placed hand driven (manually) and MSIs placed with the help of machine (reduction gear hand piece). All MSI systems feature at least one instrument for manual insertion but not all have one for use with a hand-piece. **Woo et al**[141]**,** in his study compared both MSI insertion methods. He concluded, MSIs that were machine driven exhibited high failure rate of 28% compared to manually inserted MSI, which had 11% failure rate. This can be attributed to engine driven drilling causing more frictional heat and thereby resulting in more injury to the bone tissue and cells.

Manual insertion of a MSI permits the user to get a feeling of the osseous quality at the insertion point and in turn the necessary torque. Depending on the resistance of the bone the torque applied to the MSI can be varied or controlled by the user. Whereas the disadvantage of machine driven MSI insertion is that there is no tactile feeling of resistance of the bone or load application to the screw.

Hence the MSI insertion procedure used in our study was manual, to mimic clinical scenario.

An important factor in the hand-held MSI driver is the coupling, which holds the MSI in the driver. The coupling between the driver and the screw is important for safe application of forces during insertion. Drivers with internal coupling are not considered safe for applying increased pressure. External couplings provide larger contact surface and distribute loads better and are considered safer. A feature to be mentioned is that of the safe transfer of MSI when gripped in the driver to the insertion site. Because of small MSI diameter manufacturers provide long vertical holding surfaces and ideal fit between MSI diameter and the driver to provide operator better “safe hold” while carrying the MSI. Different variations of safe hold, like slit in projection area and small metal balls in ridge are use, but they have drawbacks of wearing out, corrosion and difficulty to clean[12].

Hence, in our study the pin and tube locking device of the MSI driver was used, which provided an ideal “safe hold” for the MSI head. The MSI chosen for this study has a slot on its head, in which the in-built ledge of the MSI driver engages. This enabled the operator to engage the hand held MSI driver as close as possible to the head of the MSI and the pin and tube device then slide and lock the head of the MSI completely, thus providing a tight grip on the MSI without any wobble as seen in other hand held screw driver systems.

The surveyor assembly used in our study acted as a guide for perpendicular path of MSI insertion without any operator influence on the angle of placement[37].

Most orthodontists generally place mini-implants without a surgical guide and take only a panoramic radiograph or periapical images for presurgical treatment planning to estimate interradicular space[5,38,39,60]. When implant installation is done manually without a surgical guide, the implant tends to follow the trajectory of least resistance.[30] Complications during MSI insertion can range from slight root contact causing screw failure to extreme severe root perforation causing pulp damage or tooth loss.

Kau et al[54] suggests that even when there is apparently enough space, MSI's can be placed where they can cause damage to root structures.in their study even when the amount of space between the roots was increased by 100% amount of contact with the periodontal ligament was still high at 65.7%. Therefore he suggested that despite all good intentions and care by clinicians a more robust delivery system incorporating the 3D anatomy of the tooth might be needed soon. In evaluating the placement of MSI's on average 65.7% of the roots were in contact with the PDL space in both maxilla and mandible. These results indicate that every 2 out of 3 MSI's had contact of PDL. The numbers from 3D CBCT imaging sow a far higher number of contact to PDL than reported with traditional 2 dimensional radiographs.9 It is not yet clear whether apical positioning or an angulated placement path can reliably prevent root damage regardless of the region in the arch. If the MSI placement is technique sensitive because of complex anatomy, such as expanded sinus or alveolar bone loss, a precise surgical guide fabricated by using CBCT data should be used.

Due to all these reasons, this study was undertaken by us to evaluate the degree of deviation of MSI when placed with a guide and when placed free-hand using cone beam computed tomography.

From the results of our study,(Table 8;Chart 1,2,3) in horizontal plane (view 1) between hand and surveyor group mean angular deviation were 2.6^0 to 1.4^0 respectively. In vertical plane (view 2) between the hand and surveyor group the mean angular deviation were 1.7^0 to 1.5^0 respectively. (Table 12; Chart 4) The number of non-acceptable MSI placements between hand and survey were 187 (61.5%) and 117 (38.5%) respectively in view 1. Hence, we conclude that free-hand inserted MSIs causes more angular deviation than surveyor inserted MSIs.

In our study, in spite of using guide for MSI insertion, the angular deviation of the MSI could not be eliminated which signifies the possible role of bone density as a factor causing angular deviation.

A study by **Moriyama et al**[91] using typhodont and placing MSI with stent and free-hand placement showed that in the stent group, angular deviations in the mesio-distal and vertical directions were 1.47^0 +/- 0.56^0 and 2.13^0 +/- 1.48^0, respectively and freehand MSI placement were 7.49^0 +/- 6.09^0 and 6.31^0 +/- 3.82^0, respectively. The deviations in the stent group were significantly lower than those in the freehand group.

The result that stent guided MSI placement have less angular deviation than free-hand placement are in accordance with our study in horizontal(view1) and vertical planes (view 2). However, in the study by **Moriyama et al**[91], there were several limitations. The fact that bone density, varying MSI length and varying MSI diameter were not considered as factors might have caused higher angular deviation values for them, than in our study.

Other possible sources of error which may affect the results include the distortion in the guide fabrication process, accuracy of the radiographic image, computed tomography and cone beam computed tomography.

All metallic and surgical guides need to be individually fabricated for every patient. All surgical templates have the same disadvantages; fabrication is complicated and time consuming, requires laboratory equipment, and is expensive. Moreover, such devices do not allow the orthodontist to perform the clinical adjustments.

However, conventional periapical and panoramic imaging techniques combined with visual inspection are insufficient to obtain accurate presurgical planning because of inherent distortions of the radiographic images.

One method used to obtain an accurate surgical guide is stereolithography, but this procedure requires elaborate technology, great complexity, and high cost.[57,58,59,124] Other surgical guides can be handmade, but stent accuracy is directly dependent on presurgical radiographic standardization to avoid oblique projections and distorted radiographic images, which will lead to mistaken interpretations about a putative safe insertion site.[5,38,39,60]

Hence, cone beam computed tomography scans was used for this study.

The recently developed CBCT has overcome many of the limitations of conventional dental radiographic techniques by providing reasonable tissue contrast, minimizing blurring and overlapping of adjacent teeth, and offering orthogonal views by eliminating projection artifacts. Additional advantages of CBCT include reduced cost and significant reduction of radiation exposure compared with typical medical CT devices[67].

SUMMARY AND CONCLUSION

Numerous anatomical sites for MSI insertion have been presented in the maxilla and mandible. The inter-radicular septum is considered as one of the most commonly used locations for MSI placement. Precise placement of MSI in the inter-radicular septum is important to achieve safety of the vital structure and stability. Successful MSI placement, in both the maxillary and mandibular regions, requires accurate angulation and position in order to achieve safety, mechanical retention and primary stability. A deviation from the planned MSI insertion axis in mesio-distal and vertical direction can occur as most clinicians generally insert MSI's without a guide and place it free hand using only panoramic radiographs or periapical films to estimate the inter-radicular space, which inadvertently causes injury to roots of teeth and damage to other vital structures.

Hence, this study was done to evaluate the factors influencing the angular deviation of MSIs using cone beam computed tomography. The study evaluated factors such as varying lengths of MSI, various diameters of MSI, different bone densities and method of MSI insertion.

The conclusions drawn from this study are:-

- Increase in MSI diameter from 1.3mm, 1.5mm and 2mm causes increase in the amount of angular deviation of MSI in mesio-distal direction (view 1) and in vertical plane(view 2). 2mm diameter showed the maximum amount of angular deviation in both the planes.

- Increase in length of MSI from 6mm, 8mm and 10mm shows statistically significant increase in the amount of angular deviation of MSI in vertical plane (view 2). 10mm length MSI showed the maximum amount of angular deviation in the vertical plane (view 2).

- Increase in bone density from 10pcf, 20pcf and 30pcf causes statistically significant increase in the amount of angular deviation of MSI in mesio-distal direction (view 1) and in vertical plane(view 2). Angular deviations of MSI were maximum with 30pcf bone density in mesio-distal plane (view 1) and 20pcf in the vertical plane (view 2). Amount of angular deviation of MSI for 20pcf and 30pcf were very similar and high and it is concluded that increase in bone density causes increase in angular deviation of MSI.
- It is concluded that angular deviations with free-hand MSI insertion were high compared to guided MSI insertion in both mesio-distal (view 1) and vertical plane (view 2).

Results of our study show that as length and diameter of MSI are increased the amount of angular deviation increases in both the horizontal plane (view1) and vertical plane (view 2). 20pcf and 30pcf bone density both showed the maximum amount of angular deviations of MSI in horizontal (view1) and vertical plane (view 2). MSI inserted by the surveyor method (guide) showed decreased amount of angular deviation as compared to the free-hand placement. However even with the guide method the angular deviations are still not completely eliminated Clinically, MSIs are not always inserted using guides and as CBCT is not routinely recommended, prior knowledge of length, diameter and bone density causing angular deviation of MSI would help the clinician select the correct MSI length and diameter, for the desired MSI insertion site and avoid injuring roots of teeth and other vital structures.

Bone density showed the maximum Odd’s Ratio, denoting that it was the major factor causing angular deviation of MSI when compared to the length of MSI, diameter of MSI and the method of insertion of MSI. All these factors need to be taken into consideration before selecting the MSI for any desired placement site, to avoid injuring roots of teeth and surrounding vital structures and increase the success rate of the MSI.

The primary limitation of this study pertains to the inability to directly transfer the effects identified into the clinical situation. While the synthetic bone used in the present study is well suited for controlling extraneous factors and focusing on the effects under consideration, but angular deviation of MSI in actual bone might show much more variable and might be expected to produce different magnitudes of difference. Experimental findings should be compared to clinical studies. In vitro measurements tend to more accurately describe the variable tested; however, they are far from simulating the actual clinical conditions. Clinical studies on the other hand, may report clinically applicable data, but do not provide an insight into the specific details of the research hypothesis.

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